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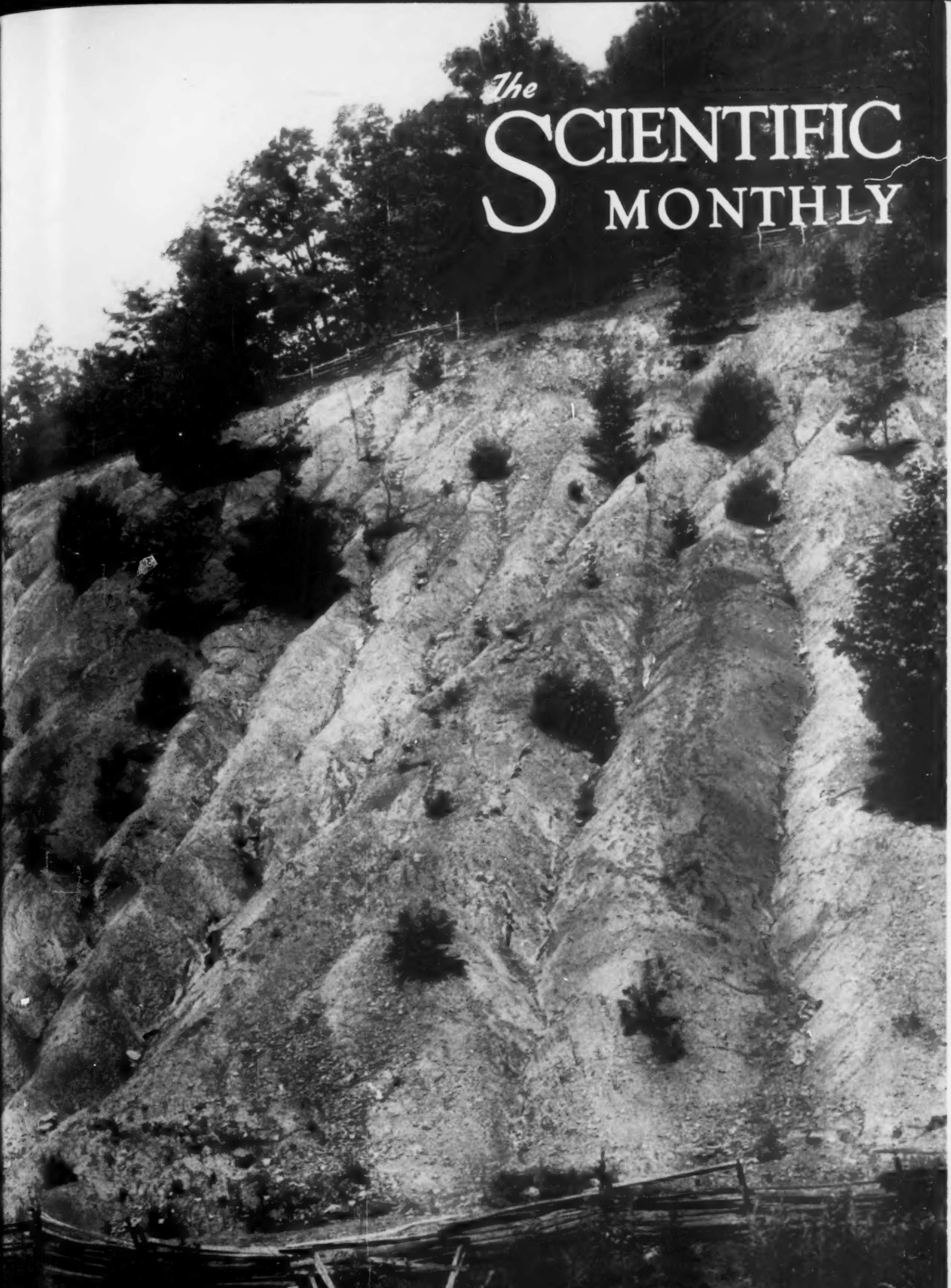

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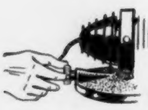

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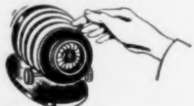

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THE SCIENTIFIC MONTHLY

NOVEMBER 1948

ELECTRONS AND COMPUTATION

W. J. ECKERT

Dr. Eckert (Ph.D., Yale, 1931) is Director of Pure Science, International Business Machines Corporation, and Director of the Watson Scientific Computing Laboratory at Columbia University. He was a member of the Department of Astronomy at Columbia from 1926 to 1940 and Director of the U. S. Nautical Almanac Office from 1940 to 1945. In 1934 he organized the first large-scale automatic computing laboratory for scientific computation. This was sponsored by IBM and Columbia University.

AT A recent ceremony in New York City, a new electronic calculator was dedicated to science. The calculator reads "written" instructions for performing the most complex calculations, has an internal "memory" capacity for instructions and problem data totaling 400,000 digits, performs the various arithmetical operations in a few thousandths of a second, and prints the desired results. Known as the IBM Selective Sequence Electronic Calculator (Fig. 1), it is located at the World Headquarters Building of the International Business Machines Corporation, where it is operated by the IBM Department of Pure Science. It was built in the company's engineering laboratories and dedicated on January 27, 1948, by Mr. Thomas J. Watson, president of the Corporation.

Actually, each operation of the Calculator could be performed by any reader of this article, given time enough; the speed and accuracy with which these operations are performed, and the flexibility and ease with which they are combined into a large calculation, are the source of the Calculator's usefulness.

With a little practice the average person could multiply two 14-digit numbers together to give a 28-digit answer in about 20 minutes; the machine does 50 such multiplications in a second, or 60,000 in 20 minutes. If the machine should make an error in an 8-hour day this would be only one error in over a million multiplications—less than one per lifetime for a computer with pencil and paper. Division requires just a little more time, and addition and subtraction of 19-digit numbers are performed in less than a thousandth of a second.

The basic capacity of 14 digits in multiplication and division and 19 in addition and subtraction is adequate for the great majority of problems; where additional accuracy is required these basic operations may be combined easily to handle numbers with 28, 42, or any desired number of figures.

To schedule multiplications, divisions, additions, and subtractions at such a prodigious rate, it is necessary to have the required numbers available at the right time and in the right order. Each multiplication, for example, requires two 14-digit numbers and generates a 28-digit answer; in other words, thousands of digits must flow into and out of the calculating unit each second. Moreover, these arithmetical operations must fit into a complicated pattern where each computed result may be one of the factors of a subsequent operation. It is therefore necessary to have thousands of numbers instantly available for use as multipliers, multiplicands, etc., and to select them as required.

This selection is made possible by providing a vast storage reservoir, or "memory" for numbers.

The memory units are devices that will accept a number, hold it until needed, and deliver it when called upon. The Calculator has a total internal memory capacity of 400,000 digits, or 20,000 19-digit numbers with algebraic signs. As the calculation progresses, results are recorded from the memory and new data are read into it. The speed of reading in and out is such that the entire 400,000 digits can be replaced in about 10 minutes.

In order to combine all these operations into a single calculation, the control facilities for instructing the machine to perform the required operations are of a very high order. The control is accomplished by a system of written instructions, which the machine reads and follows. The following are typical commands:

"Read a number from one of the reading units and store it in a given memory unit."

"Take the number from a given memory unit, multiply it by the one in another unit, drop a specified number of digits from the answer, and deposit it in a third unit."

Since multiplications and other operations are scheduled at the rate of 50 or more per second, it is necessary to supply the corresponding instructions at the same rate. To provide the necessary instructions for a complicated problem, a number of innovations in control technique have been introduced:

a) All instructions are given in numerical form. Each unit of the machine and each operation it can perform have been assigned a number, and the presence of this number in the instructions calls into action the associated unit or operation. This procedure permits the use of all the numerical facilities of the machine, not only for problem data but for handling operating instructions as well. For example, instructions totaling 400,000 digits may be stored in the machine at one time and new ones read in at the rate of 25,000 per minute. In fact, the machine can compute detailed instructions as it goes along from general outlines presented to it.

b) Each line of instruction carries with it a number instructing the machine where to look for the next command. This command may depend upon the result of a computation just completed. The commands are usually for a series or sequence of operations to be performed in a given order. At any one time a new sequence can be started at any one of about 200 places. Any given sequence can be repeated a prescribed number of times or until a given result is derived. This facility is reflected in the title "Selective Sequence."

c) Mechanical means are provided for preparing the instructions before they are taken to the machine. The basic instructions are recorded in punched cards which can be automatically checked, rearranged, duplicated, and printed to give the best procedure. Changes in instructions can be made quickly by removing a card from the deck and replacing it by a new one.

The machine records results in two forms: as a printed record and on cards which can be used for

Fig. 2. Printers which record intermediate and final results.

further work with this or other punched-card machines. Selected results are printed at the rate of 25,000 digits per minute so that the scientist can keep in close touch with the calculation as it progresses (Fig. 2).

The next question is, "How are these operations performed?" Two principal kinds of units are employed in the machine, electronic and electromagnetic. In the ordinary radio set, electronic circuits involving vacuum tubes are used to receive and amplify the radio waves. In these circuits there are no moving mechanical parts; all operations are performed by small streams of electrons which start and stop as required. In order, however, to produce audible sound it is necessary to move a material diaphragm in the loud speaker. This is accomplished by means of an electromagnet which moves the diaphragm in accordance with the output of the electronic circuits. Similarly, the Calculator employs electronic circuits and electromagnetic devices to control many of the operations. Electronic circuits are used for all the arithmetical operations, for part of the control operations, and for part of the memory; in fact, they are used wherever highest speed is required (Fig. 3). The electromagnetic devices are used to control the reading and recording of data and a great part of the traffic through the machine. The time of opera-

tion of an electromagnetic unit is a few thousandths of a second and that of an electronic unit is a few millionths of a second. The machine is so arranged that an over-all balance is maintained between the various parts. For example, a multiplication requires about 20 milliseconds (0.02 second) in the electronic unit; about the same time is required for the electromagnetic units which transfer the data into and out of the electronic multiplying unit.

The entire operation of the machine depends upon whether a current flows in a given circuit at a given time. The current or absence of current in one or more circuits in turn is used to determine whether current will flow in a third, etc. Great numbers of such circuits are operated in sequence and in parallel to give the required results. It is the efficient design and combination of these many circuits that determine the effectiveness of a calculator.

As stated previously, many of the machine operations are performed by means of electromagnets (Fig. 4). When a current flows through the coil of an electromagnet, the movable armature is attracted and moves toward the coil. By means of this device a current in a circuit can be used to inaugurate an operation such as throwing a switch in a second circuit, punching a hole in a card or in a paper tape, or printing a digit on a sheet of paper. In the Selective Sequence Calculator, 180 such small magnets are used to control the printing, 160 for punching cards, 240 for punching tapes, and 25,000 for throwing switches.

In the switching device operated by an electromagnet (a relay), the movement of the armature separates one pair of contacts and connects another pair, thus causing current to cease flowing in one circuit and to flow in another. By connecting three relays as shown in Figure 4 (lower diagram), it is possible to select 1 channel from 4 possible channels; similarly, 7 relays will permit selection from

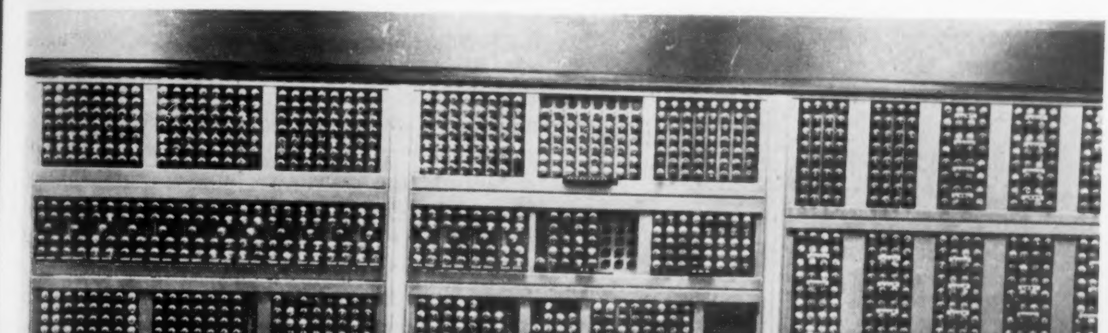

Fig. 3. A section of the arithmetical unit showing arrangement of electronic tubes that perform the basic counting operations of the Calculator.

8 channels, and so on. A single magnet may operate as many as 12 independent circuits simultaneously. In these relays the movement of the armature is only a few hundredths of an inch, and the time required for operation is only a few thousandths of a second.

Information can be read from a card or tape by means of punched holes which permit the current to flow in the associated circuits. The card or tape acts as an insulator between a wire brush and a metal roller, and contact is made through the hole in the card (Fig. 5). The presence or absence of a hole thus determines whether the current will flow when that circuit is tested.

For circuits where high speed or small current is required, the familiar electronic tube is the basic element. These tubes, or "valves," as they are called in Great Britain, are capable of switching a current off and on in the order of a millionth of a second. Such a tube consists of three elements: a glowing filament which emits a shower of electrons, a metallic plate toward which the electrons travel, and a screen, or grid, capable of interrupting the stream (Fig. 6). When the stream of electrons strikes the plate, it causes a current to flow

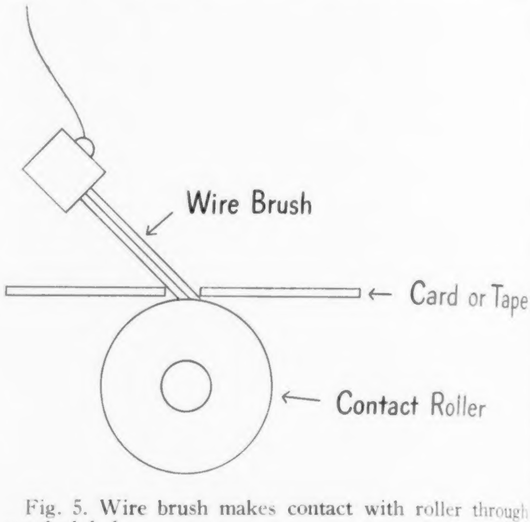

Fig. 5. Wire brush makes contact with roller through punched hole.

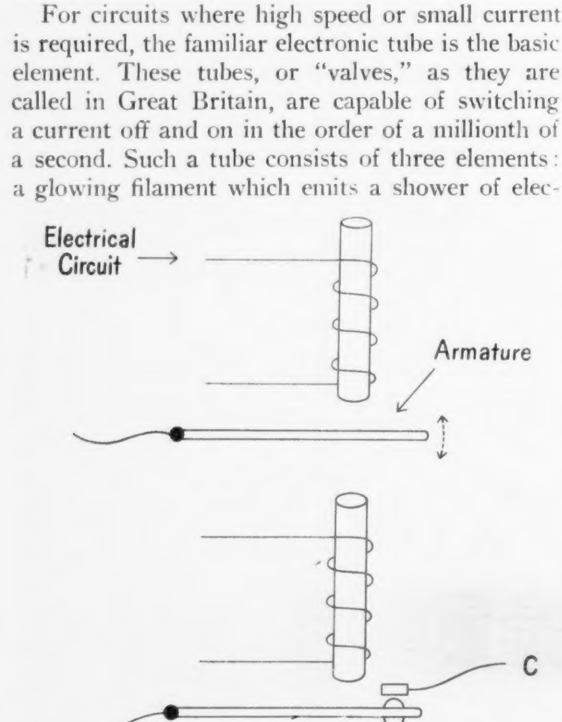

Fig. 4. Electromagnet (*upper diagram*). Armature moves up when current flows in circuit. Relay (*center*). Movement of armature breaks circuit A → B and makes circuit A → C. Three relays give choice of four circuits (*lower diagram*).

in a circuit connected to the plate. When a voltage is applied to the grid through another circuit, the stream of electrons is prohibited from reaching the plate and the current is interrupted. By proper design of the circuit such a tube may be used not only as a switching device but as an amplifier where the current so controlled is greater than that required to control it.

An ingenious electronic circuit commonly used in calculation is the so-called "flip-flop," which involves two "valves" arranged so that the current from the plate of one will operate the grid of the other (Fig. 7). This combination has the property that current always flows in one circuit and not in the other, and a slight pulse from an outside source will cause the condition to be reversed.

We come now to the assembly of the basic elements (punched-hole readers, printers, punches, relays, electronic valves, and flip-flops) into an integrated machine that will perform the operations outlined.

The initial data and basic instructions are transcribed into punched cards by means of an auxiliary device whose operation is controlled by a keyboard similar to that of a typewriter. If the problem is extensive great quantities of data and instructions will be required, and automatic methods will be employed also for checking, arranging, duplicating, listing, and editing the material. The machines used for this purpose are

standard punched-card units such as are used in accounting and will not be described here.

Fig. 6. Electronic "valve." Flow of current from plate is determined by voltage on grid.

Figure 8 shows a sample instruction card. The punching on the right-hand side of the card is the instruction data that will be read into the machine; that on the left-hand side is in the nature of shorthand notes for the guidance of the coder in examining or rearranging the cards. The pencil notes were written on the card before it was punched and the figures at the top were placed there by a machine which reads the holes and prints the corresponding characters. In the instructions to the Calculator the quantities *P*, *Q*, and *R* are the numbers of the three memory units involved in the operation; *OP* specifies the operation to be performed; *Shift* controls the position of the figures in the result; and *Seq* tells where to read the next command. *T*, *U*, and *V* pertain to a second instruction and correspond to *P*, *Q*, and *R*.

The card readers on the Calculator (Fig. 1) sense the holes in the cards by means of wire brushes, and the corresponding information is stored in the appropriate memory units. Each card reader has 80 brushes and is capable of reading as many as 80 digits from each card. Cards are fed at the rate of 200 per minute, totaling 32,000 digits per minute from the two readers. Electronic tubes are used in the reading circuits to reduce the necessary amount of current at the brushes.

The memory units of the machine are of three types: electronic, electromagnetic, and punched paper tape. In all three types the quantity stored is a simple "yes–no" condition. In the electronic storage the basic element is a flip-flop circuit, in the electromagnetic storage it is a relay which can be up or down, and in the paper tapes it is a "hole" or "no-hole." In order to save equipment, only four distinct digits are stored; the others are obtained as combinations. The code used is the so-called binary code: 1, 2, 4, 8. The four elements, taken one, two, or three at a time, will give all the digits from 1 to 9.

The electronic memory has capacity for eight 20-digit numbers and is closely associated with the arithmetical unit. This storage, with recovery time of less than a thousandth of a second, permits the performance of small sequences of operations independently of the electromagnetic part of the machine.

The electromagnetic storage provides for 150 20-digit numbers. These numbers are available in any order, and the selection time is equal to the time of a multiplication, or 20 milliseconds. Eight different routes are provided for transferring numbers from this storage to the electronic units to permit simultaneous transfer.

Storage for 20,000 20-digit numbers is provided in the form of punched tapes, each line on a tape corresponding to one number (Fig. 9). There are 3 punching units and 66 reading units; the punching, selection, and moving of the tapes are all controlled electromagnetically. Selection of any one of the tape readers is equivalent to selection from electromagnetic storage (0.02 second). Punching in each of these units requires about 40 milliseconds. The tapes may be moved at the rate of 20 milliseconds per line; i.e., 1,000 digits per second passing a given reader.

Thirty tape-reading units are associated with the 3 punches, so that a number recorded by the punch may be read back later as it passes the successive reading stations. Each punch is followed by 10 reading stations, or the tape from the first

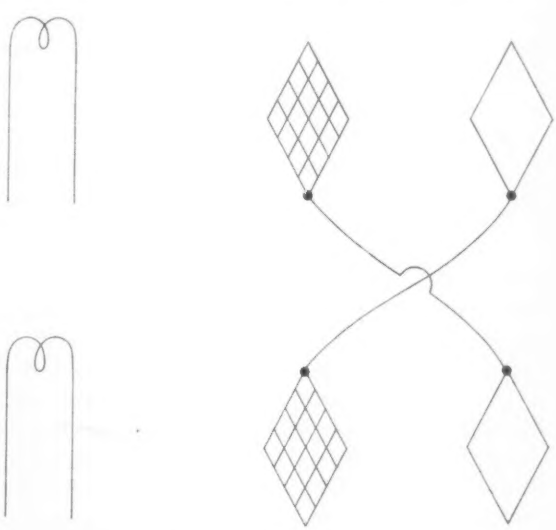

Fig. 7. Electronic "flip-flop."

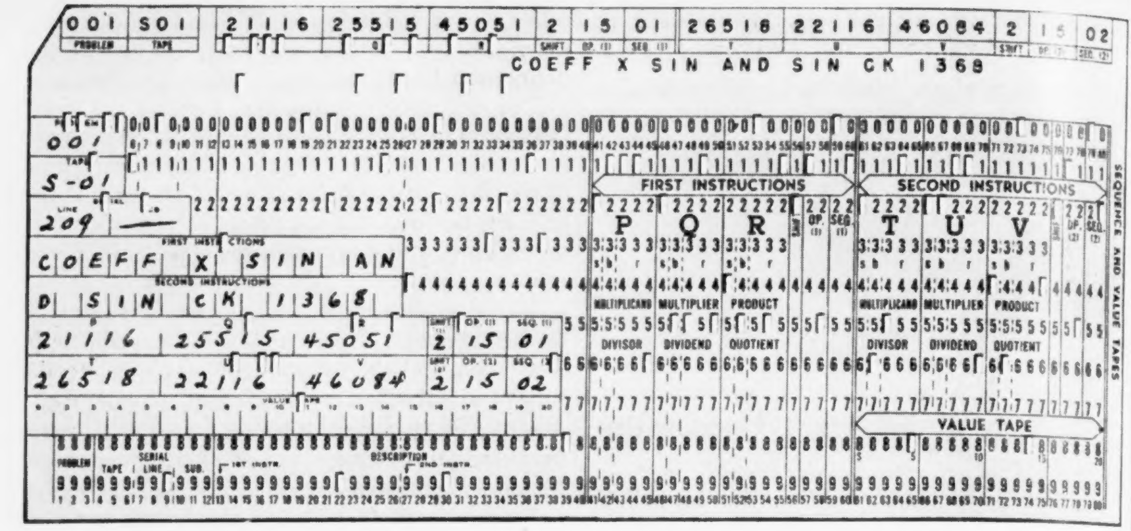

Fig. 8. Numbers that enter into computations and those that direct the operations of the Calculator are read from punched cards.

punch may pass to all 30 reading stations. Each reader can handle either continuous tape or closed loops (Fig. 10).

Thirty-six other tape readers are associated with a searching mechanism, so that any desired data may be quickly located. This unit has a capacity of 100,000 digits, and a complete search may be made in an average time of 1 second. This unit is used for consulting large mathematical tables containing such data as sines, exponentials, cube roots, etc. In all cases the machine computes a quantity for which a given entry in the table is required. In this unit a table with arbitrary intervals of the argument may be used.

We have already stated that the operations of addition, subtraction, multiplication, division, and column shift are performed electronically. These operations are accomplished by the proper combination of switching circuits and flip-flops. The flip-flop can be arranged so that successive pulses over the same wire will cause it to flip and flop alternately. A combination of such units serves as a counting device for counting a succession of pulses. The first pulse causes the first device to flip; the second pulse causes it to flop and also to flip a second unit, and so on.

Obviously if a device will count, it can add. If it can add, it can multiply by repeated additions. By proper combinations of such devices all the arithmetic operations, as well as switching and memory, are possible. All these operations are performed at great speed and with no moving parts.

The printing units have an output of 30,000 digits per minute. The records produced are for permanent reference and also for inspection as the calculation progresses. Since the machine is fast and is used for research work where it is not possible to foresee all contingencies, it is essential that the scientist be able to follow the work closely and modify his instructions in the light of the results as they appear. Recording on punched cards, at the rate of 16,000 digits per minute, supplies additional unlimited storage if the 400,000 digits in the machine are inadequate. It also provides data in a form for further processing or publication by mechanical means.

The natural questions at this stage are: "What part does such a calculator play in science?" "What is the nature of the problems which will be put on it?" and "How can the work be planned to take advantage of such great speed and capacity?"

In all fields of science, physical and social, pure and applied, it is necessary to make observations and to fit them into a theory. In order to increase his powers of perception the observer uses instruments such as telescopes, microscopes, thermometers, and galvanometers. Similarly, in order to increase the effectiveness of his reasoning powers, man requires mechanical devices. The classical example of this need is in the application of Newton's laws of mechanics and of gravitation. It is possible to state these laws in a few sentences, but their application to the various crucial cases has required the greatest efforts of mathematicians and

astronomers for a century and a half, and the work already done is just a beginning. In every field of science there are similar problems.

To a great extent it is possible to substitute one for the other: mathematical theory, computation, observation. For example, in designing a new airplane three approaches may be used: predict analytically what will happen, predict computationally what will happen, build it and try it. The ability to make extensive calculations quickly and efficiently will advance all phases of science.

The following is a very simple example of how a problem can be put on the machine. This problem requires only a negligible part of the storage facilities of the machine, but it illustrates the exercise of choice at various stages. In the computation of the electron field of an atom, the solution of the necessary differential equations can be obtained by a numerical process which builds a table of numbers representing the desired quantities. The computation proceeds from one line to the next, each depending upon the previous line. In each line there will be five quantities: the number of the line, n, a precomputed number, q, for that line, and three quantities, x, y, z, which are to be computed for each line.

n	q	x	y	z
1	. . .	. . .	. . .	. . .
2	. . .	. . .	. . .	. . .
3	. . .	. . .	. . .	. . .
.	. . .	. . .	. . .	. . .
.	. . .	. . .	. . .	. . .
.	. . .	. . .	. . .	. . .

The formulas are such that when x, y, and z for a given line have been found the value of x for the next line can be computed; when the value of x in a given line is available the values of y and z in that line can be computed. The computation is thus performed by the use of two alternate procedures. The formula for computing x is

$$x \text{ (new line)} = 2\,x \text{ (previous line)} + y \text{ (previous line)} - x \text{ (second line previous)} \qquad (1).$$

The formulas for computing y and z from x and q are

$$z = x + 1/12y \qquad (2);$$

$$y = (1/4 + q\sqrt{z})\; q\, z \qquad (3).$$

Equations (2) and (3) are solved by successive approximations: by neglecting y in equation (2) an approximate value of z is obtained; this is substituted in equation (3) and an approximate value of y is obtained; this is substituted in equation (2) to obtain an improved value of z. The process

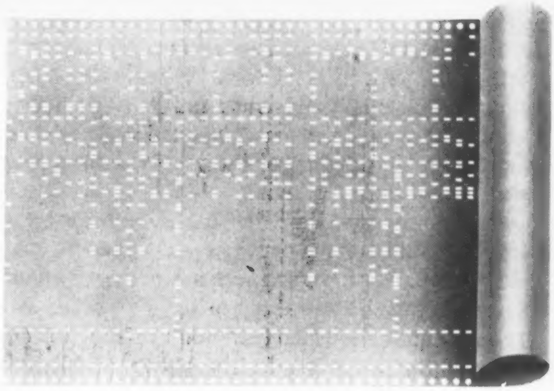

Fig. 9. Punched tape. One line (vertical) permits storage of 19-digit number.

must be continued until the two equations are satisfied to the required accuracy.

When this line has been completed the same procedure is followed for the next line. The table is to be extended until the value of z satisfies one of two conditions: it becomes greater than a specified value, or two successive values bear a prescribed relation to each other.

The programming of the Calculator for this problem is as follows: the instructions for carrying out a cycle of the solution of equations (2) and (3) are contained in a loop of tape so that one revolution of the tape on the reader corresponds to one approximation. At the conclusion of a revolution of the tape the new approximation to z is compared with the previous value. If the agreement is within the prescribed tolerance the cycle is not repeated; if it is not within the required tolerance another cycle is performed.

At the completion of the sequence of approximations the resulting value of z is tested for compliance with one of the two conditions for ending the table. If the stopping point has not been reached a new value of x is computed and then another y and z.

The square root operation necessary for equation (3) was not listed as one of the "built-in" operations of the machine. A subroutine for this operation is therefore made up on a loop of control tape and operated in much the same manner as that for the solution of equations (2) and (3). This loop of tape instructs the machine to take an approximate value of the square root and improve it, the first approximation being the value used in the last previous computation. At the completion of each cycle the result is compared with the previous value and the process repeated until the required precision is obtained.

The above procedures usually required about 60 lines of the table, involving about 7,000 lines of instructions, of which 24 were written out; 5,000 multiplications; 500 divisions; and 9,000 additions and subtractions. They are completed in 5 minutes. A considerable number of integrations were performed for different starting values, the new starting values in each case being determined by a quick inspection of the previous record.

In extending the computation to the diatomic molecule it will be necessary to solve a partial differential equation which will require the full capacity of the machine. In the above problem it was necessary to operate on only a few lines of the table at a time; in the next case it will be necessary to consider a two-dimensional array of numbers which will run into the thousands.

Another problem that has been put on the machine is that of computing the position of the moon for any time, past or future. The equations are read into the machine, and when a given date is supplied the machine computes and checks the required results. For this computation an eight-place sine table is used. At one stage of the computation a small table is read into the electromagnetic memory, used 800 times in 3 minutes, and erased to permit use of the memory for other parts of the calculation. A summary of the data and operations involved in computing and checking one position of the moon is given in Table 1.

TABLE 1

Digits in basic input data and instructions	165,000
Additions and subtractions	10,710
Multiplications	8,680
Table look-up operations	1,870
Lines of sequence instructions required	1,170
Lines of sequence performed by calculator	10,350
Time required	7 minutes

Calculating devices are usually classified as "digital" and "nondigital," according to whether the basic operation depends upon the counting of discrete units or the measuring of physical quantities. The machine we have just discussed is of the digital variety.

Familiar nondigital devices include the slide rule, the planimeter, and computing gun sights. Some of the latter devices are large and elaborate. Among the large fixed computers are the "Network Analyzers" used in computing performance of power networks, and the "Differential Analyzers" at Massachusetts Institute of Technology and other places, which are used in the solution of differential equations. Digital calculators include adding machines, desk calculators, keyboard accounting machines, and punched-card computing and accounting machines.

Until the past few years practically all digital calculators operated by means of the adding wheel. In all cases except one these wheels are actuated mechanically; in IBM machines they are operated by means of electromagnets. The IBM Automatic Sequence Controlled Calculator at Harvard University (1944) contains nearly 2,000 such wheels.

During the past decade a number of large calculators have been constructed using the relay as a basic unit. These include several built by Bell Telephone Laboratories and by IBM; another has just been completed at Harvard. The largest previous electronic digital calculator, known as the ENIAC, was built by the University of Pennsylvania. This calculator has an internal memory

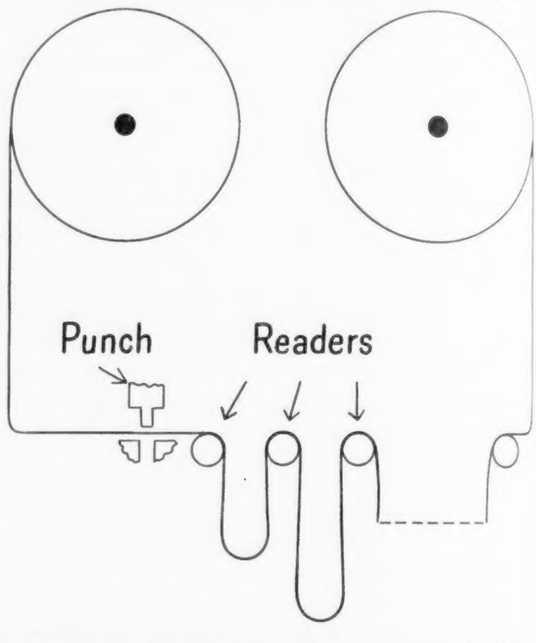

Fig. 10. Schematic diagram of tape memory unit. Numbers are punched in tape and read back at successive readers.

capacity of about 200 digits, and its operation is controlled by means of pluggable connections.

At the present time a great deal of research is being devoted to the further development of electronic calculators, particularly in the development of the memory element. Various devices have been proposed for this purpose, such as the supersonic delay line; the electrostatic tube; magnetic drums, tapes, and wires; and photographic film.

The supersonic delay line usually consists of a column of mercury so arranged that vibrations set

up in one end will travel to the other end and be detected. As they are received by the detector they can be used or recirculated repeatedly until needed. The electrostatic memory device is somewhat analogous to the projection tube in a television set. A stream of electrons impinges on a surface and produces small charged spots that can be detected later. Magnetic drums, tapes, and wires employ small magnetized spots on a metal surface. The method is similar to that used in magnetic sound recording. Small spots on a photographic film with photoelectric detection is another type.

We have seen how the Selective Sequence Calculator was designed to save equipment by coding each decimal digit as a combination of the binary digits, 1, 2, 4, 8. Some further saving would be achieved by coding larger numbers in the same manner: 1, 2, 4, 8, 16, 32, . . . This saving in equipment must be considered in relation to the difficulties involved in converting large numbers from the decimal to the binary notation and vice versa.

PHYSICIST'S WINTER

Abruptly evening shrinks the capillary
Metal in its threadline, narrows sky
To pinpoints; ice-light races time
From source-eternal. Footprints in the slush—
Eutectic harden into molds with
Crisp and crumbling edges for our nightsteps,
Nearer to the door. No meadow wanderer
Seeks out a known-green world in such
Decreasing entropy; ice-wands
Cling brittle to a board, then stolidly
Clitter with falling, this being season
Blessed by a parallel-vectored wind
And notably devoid of calories.

HENRY A. HOFFMAN

WHAT IS NATURAL SELECTION?

S. J. HOLMES

Dr. Holmes (Ph.D., Chicago, 1897) is professor emeritus of zoology at the University of California, Berkeley. Well known for his studies in genetics and eugenics, he has been called "one of the deans of American biology." His latest book, Organic Form and Related Biological Problems, *was published this year by the University of California Press.*

IT MAY seem a strange anachronism in these days to be discussing the meaning of the term "natural selection." Everyone, of course, now knows what natural selection is—it is the survival of the fittest. Organisms vary. Some variations are better adapted to their conditions of life than others, and, on the average, the favorable ones are preserved and the others perish. This is natural selection. It is all very simple. Why, then, should anyone dwell further on so trite a topic?

It requires, however, no great familiarity with the vast literature on natural selection to realize that different people have interpreted this process in very different ways. Since the term natural selection was first employed by Charles Darwin, it would seem proper to accept the meaning originally given to it. In the fourth chapter of the first edition of the *Origin of Species,* Darwin stated that "This preservation of favorable variations and the rejection of injurious variations, I call Natural Selection." In later editions he added the phrase "or the Survival of the Fittest," which he adopted from Herbert Spencer. As thus defined, natural selection includes a twofold process or, rather, two sets of processes: those concerned with the preservation of certain variant individuals and those responsible for the destruction of others. And an essential feature of the whole series of activities is that the fate of the individuals involved is to a significant degree dependent upon what they inherit. Mortality having no relation to endowments, such as the destruction of all the inhabitants of an island that sank into the sea, would not come under the head of natural selection in the Darwinian sense.

As will be pointed out later, it makes a deal of difference in one's evaluation of natural selection as an evolutionary factor whether its preservative phase is included in the process. It has too often been asserted that natural selection is merely a negative factor, creating nothing, but only destroying those organisms that fail to meet the requirements of their environment. St. George Mivart, for instance, refers to natural selection as "an apparently positive name for a really negative effect, and is therefore an eminently misleading term. By 'Natural Selection' is meant the result of all the destructive agencies of Nature," thus ignoring completely its preservative influence, which is clearly stated in the original definition of the term. And E. D. Cope states that "nothing ever originated by natural selection. It is to the great causative forces as are the gutters and channels which conduct the water in comparison with the pump and the man who pumps it." A similar conception is not uncommon among the opponents of Darwin's theory, to whom it may have appealed, consciously or unconsciously, because it makes destructive criticism so very much easier. The real creative force in evolution, it is asserted, is afforded by those causes that give rise to new favorable variations without which it would not be possible for natural selection to make any advance.

But if we grant this contention it does not follow that natural selection is not a causal factor. Samuel Butler takes Darwin to task because he spoke of natural selection "as if it were an active cause (which he manifestly does)." Any kind of selection, natural, artificial, or sexual, is obviously a process or, rather, a series of processes unavoidably including a lot of sequences which can hardly escape being active causes of something. Accepting Darwin's definition that natural selection is the preservation of favorable variations and the destruction of unfavorable ones, it will prove instructive, I think, to carry out its logical implications and see where they land us. We shall find that we will be led to some conclusions that many writers on the subject have apparently never thought about before. The implications of this simple word "preservation" are really tremendous. Both the processes of preservation and destruction include the operation of numerous causes, internal and external. On its preservative side we

cannot stop short of concluding that natural selection embraces the manifold physiological activities that preserve the life of the organism, and also the numerous formative processes of embryonic development. It may also include useful behavior reactions, resistance to disease, and the effects of many environmental conditions without which the organism could not persist. The preservation of favored variations necessarily includes all these activities, and more.

Nothing could be simpler than the general formula of natural selection. But when once we begin to inquire as to what is included in these processes of preservation and destruction in which natural selection consists, we encounter a vast number of factors whose complete analysis is a hopeless task. There can be no doubt that natural selection in the sense defined is actually operative in the organic world. It gives us a very plausible explanation, so far as it goes, of why certain peculiarities of organisms came to be as they are. This is an important achievement, even if it represents only a first step in the process of causal analysis. It profoundly affects our interpretation of the phenomena of adaptation, which is so conspicuously exemplified in the world of life. It has severely shaken the general confidence in the argument from design, which has long been defended for the consolation of the faithful and the discomfiture of the skeptic. Its theoretical bearing is especially important if the largely unknown causes in terms of which its explanations are made can be assumed to be natural as this term is commonly used. Darwin assumed that these causes are natural; his theory, he held, could get along under that assumption, and, as a matter of fact, we know that many of them are. It may be contended, of course, that some of them are not, and that they require the action of purposive agencies of some kind, but the burden of proof, as in other scientific problems, lies with the proponents of such a view.

If we include under natural selection the numerous causes that lead to the preservation of favorable variations, how far back should our series of events extend? Should it include the production of new variations? On this point Darwin makes the following remark: "Some have even imagined that natural selection induces variability, whereas it implies only the preservation of such variations as arise and are beneficial to the being under its conditions of life." We may assume, then, that the processes concerned with preserving or destroying a given individual, which are properly included under natural selection, are those that follow the origination of the new variation. As to why variations arise, Darwin had little to offer, but he regarded them as quite as natural ("given by nature") as any other event.

It has been customary to consider variation and selection as different processes that cooperate in effecting evolutionary changes. A closer scrutiny of these processes, however, gives rise to some interesting questions concerning the distinction, which may have to be decided in an arbitrary manner. Apparently the production of a new variation is something quite different from its survival. As we commonly picture the process, different variations present themselves somehow and some of them are preserved and others destroyed. But if a variation appears it obviously must be produced. If it is produced, it must have been preserved, at least up to a certain point. If it continues to survive while others perish, the formative activities that lead to its being different (a new variation) are but a part of the preservative activities that enable it to live. The common conception of a new variation as something given in its entirety independently of natural selection, and upon which natural selection may work, is quite indefensible, because without the preservative activities that constitute natural selection the new variant organism could not appear at all. Even a variation that is eliminated must be preserved by natural selection for a time at least. If on account of some lethal factor it is destroyed at an early embryonic stage, the integrative activities which are at first successful are overcome by destructive factors which later prevail. Natural selection is both Vishnu, the Preserver, and Siva, the Destroyer. Some organisms may develop no further than a germ cell. From the standpoint of the species the fortunate ones are those that are able to persist through the reproductive period of life. Every new variation that gets beyond the stage of a modified germ cell, therefore, requires the aid of Vishnu if it reaches any particular period of development.

The new variations presented for the operation of natural selection are those in which a germinal change of some sort is but one factor in its formation among many others essential for its preservation. If a germinal modification is preserved to following generations, it takes its place among the complex of conservative genetic factors that perpetuate the successful stock. Then its function comes under the category of natural selection, and its influence helps to determine whether a subsequent new variation will survive or perish.

When we attempt to abstract and set apart the processes of variation and selection we find that

they are very intimately associated. The only way in which we can hope to make a sharp distinction between them is by limiting the former to the germinal change which, working with other influences, eventuates in a different kind of organism. Throughout evolutionary literature, from Darwin down, variations have been assumed to constitute the precondition for selection. But it is only the germinal change that antedates selection. This change may, of course, be essential to survival, or, again, it may lead to a fatal result.

In the process of abstraction by which variation has been sharply set apart from selection, a variation has commonly been conceived as a more or less completed product, such as an Ancon sheep or a runnerless strawberry. In this procedure the fact that has been generally overlooked is that what has been abstracted from selection (the production of a variant organism) is in large part the effect of selection. The abstraction is only partial, but many of the arguments based on it have proceeded on the assumption that it is complete. As commonly conceived, what is presented somehow for natural selection to work on is a definitely formed organism, such as a long-bodied sheep, without reflecting that without the preservative action of natural selection such a variation could not appear.

For a long time (until the time of Weismann) germinal variations were, as a rule, not clearly distinguished from those occurring in the soma. Darwin was much less explicit on this matter than he might have been, but even after this distinction was clearly recognized, writers continued to speak of the production of a variant organism as quite different from the processes of selection by which it is preserved.

We should always bear in mind that natural selection is a name for a group of processes that make for the preservation of an organism or its destruction as a result of its inherited constitution. It is not mere survival or extinction considered as a terminal event. The preservation of favored races necessarily includes very numerous activities involving a multitude of causes. And it is important to consider it from this dynamic standpoint and what it implies in any discussion of what natural selection can and cannot do. Natural selection is just as creative as the work of the selective breeder. Both attain their results through the preservation of variations that are good enough to appear; and natural selection must cooperate with the breeder if he creates a desired product. If his chosen candidates for parenthood fail to maintain themselves or do not behave in the normal, expected way, he can accomplish nothing. The breeder is just one environmental factor which, like many others, determines the kinds of variations that survive.

The activities embraced under the term preservation are to a large extent the work of genes which at some time arose through mutation, or they are the product of some other kind of a germinal change. The new mutants that are perpetuated must be, in a sense, selected by the conservative outfit of factors with which they have to get along effectively if they become incorporated as integral parts of the modified aggregate. We are thus led to consider an aspect of the action of natural selection which has been generally overlooked or ignored, especially in the older literature. It is the fact that selection has operated through the preservation of those variations in genetic factors which fit them for acting in harmonious social relationships. As I have elsewhere contended (*Organic Form and Related Biological Problems*. Berkeley: Univ. of Calif. Press, 1948, 11, 27, 28, 33, 34), the fact that natural selection has been so much concerned with the reaction modes involved in formative processes that concur in the production of a living organism helps us to understand many apparently purposive features of organic behavior which have frequently been adduced in support of various brands of vitalistic theory. From this viewpoint the ability of organisms to make appropriate direct responses to varied situations becomes a much less formidable difficulty to the naturalistic biologist than it formerly appeared.

A very large proportion of organisms are eliminated because they do not possess sufficient intrinsic viability to survive under the most favorable of all possible environments. The large number of mutations which are lethal at one stage or another affords strong evidence for this conclusion. The elimination of an amaurotic idiot or a homozygous yellow mouse is not a consequence of any failure to respond properly to some environmental influence, but is a consequence of the disharmonies of its inner formative mechanisms. Life is not only the continuous adjustment of internal relations to external relations, as it was defined by Spencer, but the adjustment of internal relations to other internal relations. If any organism is to survive, therefore, its genes must be selected in a very special manner.

Since the new germinal variations that are added have to fit into the existing complex of genetic factors, this complex may be said to select

its members after the fashion of an exclusive club. And the club to which the genom may be compared blackballs the great majority of its candidates for admission. The survival of the organism must depend primarily on the aptitude of its members for getting on well together. The groups in which the constituents behave at cross-purposes quickly go into the discard. The novelties that result in improvement are, as we must expect, relatively rare. The self-perpetuating assemblage of genetic factors is mostly a well-orderd body whose members for the most part cooperate most admirably to promote the common weal. Government, as in societies of insects, seems, on the whole, to be on a democratic basis, which, after all, is the organismic method of regulation.

The origin of new germinal variations includes, of course, other happenings besides changes in individual genes. There are variations due to an increase or decrease of chromosome numbers, duplications of parts, translocations, and various other unusual procedures that give rise to transmissible modifications which may result in elimination or, much more rarely, in the production of a superior strain. The causes of these changes, like those of gene mutations, are multifarious, but it is a significant fact that a number of causes, including X-rays, etc., are productive alike of both classes of hereditary variations.

As before stated, Darwin distinguished sharply between the production of variations and the selective processes which decide whether a given variation survives or perishes. This distinction seems so very obvious because new variations appeared as unaccountable happenings which afford the condition for subsequent change. The new light which has been thrown upon the nature and the different kinds of variations, on the one hand, and what is known of the numerous procedures involved in the preservation of favorable varieties and the destruction of misfits, on the other, give us a concept of the relation between variation and selection that in some respects differs from that in the mind of Darwin.

To the extent that one is a Lamarckian, as Darwin was to a mild degree, he would not be justified in concluding that natural selection is unable to cause variability. This is because somatic modifications, according to Darwin's definition, must fall under natural selection, if they tend to preserve the organism. So far as these modifications are transmitted to following generations, thus far natural selection must be regarded as a cause of variability.

But, when we consider the topic from the standpoint of the orthodox neo-Darwinian, the distinction between variation and selection becomes less obvious than it was formerly held to be. Among the happenings that take place in the normal life of an organism, there are marked changes in gene activity, changes in the number of genes, and changes in plastids and other possible gene derivatives. Presumably we should include under variation the occurrence of mosaics, bud variations, and mutable genes, but there are other happenings concerning which there is more uncertainty as to the heading under which they should be classed. Whether the origin of a malignant cell is due to a somatic mutation is still a matter of dispute. There is, as yet, no unanimity of opinion on the nature of viruses. It has been conjectured that they are free genes, and again that they are modified descendants of genes, or perhaps in some other way products of the organism's own metabolism. Then there are the Dauermodifications, which may give rise to different competing strains. If these should turn out to be dependent on cytoplasmic changes similar to those occurring in the specification of cells in normal development, the distinction between variation and selection would perhaps have to be drawn on a purely arbitrary basis. There are plenty of discrete, mutationlike changes in the organism during its formation. To be consistent, we should have to class all true gene mutations or chromosome aberrations as variations even if they affected no more than a single cell. Whether such variations play at times an indispensable role in normal development, we cannot be certain. Quite evidently, however, they may cause the elimination of the organisms in which they occur.

In the stream of events which constitute the process of organic evolution there are, in addition to the preservation or destruction involved in selection and the origination of new germinal variations, a third category of phenomena, which are indifferent in that they have no relation to survival or extinction. Their production, therefore, is not directly attributable to natural selection, although they may often be incidental consequences of the formation of useful characteristics. They have often been adduced as constituting a serious difficulty for Darwin's theory. But inasmuch as most heritable variations are bad or indifferent, their accumulation within limits is nothing to be wondered at. And where species produce many times as many progeny as can possibly survive, they may be able to carry a considerable burden of useless characteristics.

When we consider the ways in which writers on evolution evaluate the relative importance of

selection and the causation of variability, we encounter a great range of opinion. As to the causes of variation, the divergencies have been wide. There have been appeals to variation divinely initiated, to a perfecting principle, to an entelechy, to an *élan vital,* or some other factor working orthogenetically, to Lamarckian inheritance, and to various other alleged causes. There have been also very different degrees of importance ascribed to selection, from its all-sufficiency to a virtually negligible role, or even none. In the light of the greatly increased knowledge of variation and its different kinds which has resulted from the advances in genetics, it can be truly said, I think, that most of these views on the causes of variation have received no support. Those variations due to Mendelian segregation follow the same rules of chance exhibited in tossing pennies. Those caused by X-rays, ultraviolet radiation, heat, or bombardment with neutrons have the appearance of being almost equally fortuitous, although with a vastly greater range of possibilities. One cannot state, however, that they are completely indeterminate as to direction. But the whole picture of variability gained from observations of mutations arising spontaneously and those experimentally caused goes far toward justifying the application of the term "fortuitous" employed by Darwin.

Looking upon selection in the way I have described, it is evident that once a germinal variation has occurred it affects the perpetuation of all the genetic factors that produce the organism. Generation after generation new or modified genetic factors are added to the stirp, which builds up its own membership in ways that enable it to meet two different classes of requirements. One of these, for want of a better name, we may term "intrinsic viability." It requires a great deal of mutual adaptation of genetic factors to produce a living organism even under the most favorable conditions, and defects of genetic factors lead to an enormous amount of elimination. The other class of variations is, of course, those affecting, for better or for worse, the organism's reaction to its environment. These two classes are not entirely distinct, but are associated in various degrees of intimacy. The action of some formative factors may be almost completely independent of all environmental influence. A modified response to the environment, however, cannot be independent of formative factors for the simple reason that it is dependent upon them for its existence. The structure and reaction modes of such diverse creatures as an ant and an anteater are presumably the outcome of accumulating genetic variations which not only fitted the ancestors to meet the demands of their conditions of life, but also the intrinsic viability requirements of morphogenesis.

It may seem to many that I have employed the term natural selection in too wide a sense because I have included in it the multitudinous phenomena of development, the physiological activities of all parts of the organism, its behavior in relation to external objects and conditions, and the effects of the environment on the life of the individual. We do not usually think of selection as including all these elements. We look upon it, much as Darwin did, after the analogy of the breeder who picks out certain individuals and rejects others. But when we substitute nature for the selective breeder, we must take the logical consequences of our procedure. The term nature has a *very* comprehensive denotation. When we speak of the preservation of a favorable variation, we cannot limit this process to a single act comparable to the choice of a breeder. We are logically driven to include all the stages involved in its production and all the processes responsible for each. When, therefore, we accept Darwin's definition of natural selection, we are using the term to cover a great multitude of causes in so far as they may properly be defined as natural.

In setting forth some rather obvious though not frequently discussed implications of the theory of natural selection as defined by Darwin, I have not, I hope, been dealing with a topic devoid of any theoretical bearing. If we include under selection the various natural processes I have indicated, it is impossible to maintain that natural selection is a purely negative influence. Without variation it may not create a new species. Neither can variation without the preservative action of natural selection. The preservative activities of morphogenesis are certainly creative even when they do not create anything new. But within limits they create new forms and new adaptive forms, although they may not be new genetically. All the adaptive activities of any organism after it has received its complement of genetic factors must be credited to the function of preservation. The nature of these adaptive responses may be looked upon as the outcome of previous genetic variations. Variations condition the direction followed by evolution; the organism determines what variation fits in with it in a way that leads to survival. Out of the multitude of different possible variations it selects those which are congruous with its own constitution not only in relation to intrinsic viability, but in relation to making adjustments to the environment. A tendency for variations to accumu-

late in the same general direction would seem to be a natural consequence of this fact.

It is no reproach to Darwin's theory that it does not account for the origin of variability. That variations occur in abundance, that their origin is presumably natural, and that they occur in very numerous directions and can be accumulated by selective breeding were facts that afforded a sufficient basis for his theory. Darwin believed that variability might be induced by the environment (nutrition, temperature, etc.) and to a certain extent as a result of Lamarckian inheritance, but for the chief purposes of his theory he could afford to take variations as "given by nature."

The attempt to throw light upon the mechanisms concerned in natural selection brings us at once into the fields of biochemistry, physiology, experimental embryology, and other branches of physical and biological science, and at times into psychology and the social sciences. We thus become confronted with a great variety of problems requiring special applications of principles belonging to many disciplines. Natural selection is confessedly a figurative expression based upon an analogy with the work of a selective breeder, but with the breeder replaced by nature in all her manifold complexity.

It is true that when we apply the simple selection formula to explain any feature of evolutionary change, we have usually done little more than to attribute it to natural causes. In Darwin's time this was an important achievement, for it substituted explanation in terms of natural law for supernatural intervention. If natural selection makes only the first step in the direction of a complete explanation, it directs the efforts at further analysis into two fields, the search for the causes of variability, and the study of the forces that lead to the preservation or destruction of variant types. In both these fields investigation has yielded a large body of significant facts. The discoveries that have been made concerning the nature of different kinds of variation and the agencies by which new variations may be produced have been of particular importance for our views on the method of evolution. By many writers the causes of variation have been stressed as the all-important problem for evolutionary theory. The idea that variations occur with little regard to direction, as if they were mostly fortuitous happenings, has met with vigorous and widespread opposition. That variations can arise by chance or, in other words, that they result from so large a number of causes that their nature and direction cannot be predicted, has been looked upon as an especially shocking conclusion. Out of such a chaos of hit-or-miss happenings an orderly, progressive evolution, it was alleged, could not possibly occur. Hence, the many efforts to find some internal source of variability that proceeds consistently along definite lines, such as Nägeli's perfecting principle, Fechner's stability principle, the *élan vital*, and various others. These alleged causes of variability are little more than names for what it is that causes variation to be produced in definite directions. As to the specific mode of producing their effect, they are peculiarly unenlightening. They are generalizations drawn almost exclusively, not from experiments on the actual production of variations, or from observations on the ways in which variations occur, but from inferences on the ways in which they must have occurred to produce the line of development they have been assumed to follow. From the standpoint of these theories the direction of evolution has been determined mainly by whatever it is that causes variation to follow consistently a particular course, natural selection being relegated to the role of eliminating the misfits. According to the Darwinian viewpoint, since variations occur in a large number of directions, the course of evolution is guided chiefly by natural selection. So far as experiments have thus far thrown light on the causes of hereditary variations, and so far as observations have gone as to the many kinds of variations that appear, the preponderance of evidence at present available is, I believe, distinctly in favor of this view. If there are any forces slowly acting to produce evolutionary changes along predetermined lines, their existence has not yet been revealed.

As I have pictured the intimately related processes of variation and selection, using the term variation as a change in the genetic factors that results in a modified organism, it is obvious that such changes are essential for the production of new types by natural selection. At the same time, natural selection is essential if the modified germ plasm produces an organism at all. Probably natural selection has not usually been looked upon in this way simply because people have not reflected upon what is involved in the "preservation of favorable individuals or variations." After all, the importance of germinal changes in evolution is not so much how they are caused as what they do afterward. When they lead to survival and become more or less permanent constituents of the stirp, their functioning becomes an integral part of the preservative activities that constitute natural selection. In fact, a mutant gene becomes an in-

strument of natural selection as soon as it begins to act.

For the purposes of Darwin's theory, variations, whatever the means may have been by which they were "given by nature," could always be made use of by natural selection. Where many different kinds of germinal variations are produced, evolution is free to follow a large number of different lines. The almost inexhaustible varieties of structural pattern that have been formed and the multitudinous adaptations that occur in relation to specific external conditions, both inorganic and organic, afford convincing evidence that the course of evolution has ever followed the beck and call of opportunity. For this to have been possible a great diversity of germinal variations must have been repeatedly produced, however they may have been caused.

LEAF HOPPER STYLETS IN SUGAR-BEET PETIOLE

THIS INTERESTING PHOTOGRAPH WON HONORABLE MENTION FOR CHARLES F. LACKEY, PLANT PATHOLOGIST, USDA, RIVERSIDE, CALIFORNIA, IN THE BLACK-AND-WHITE DIVISION, 1948 INTERNATIONAL PHOTOGRAPHY-IN-SCIENCE SALON.

EPIDEMICS AND BACTERIOLOGICAL WARFARE

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A native of Colmar, France, Dr. Mayer studied medicine and chemistry at the Universities of Strasbourg and Freiburg. Prior to coming to the United States, he was engaged in research in allergy and chemotherapy. He is at present chief microbiologist in the Research Department, Ciba Pharmaceutical Products, Inc., Summit, New Jersey.

SCIENTIFIC research has two primary objectives: one highly theoretical, the other highly practical. The theoretical objective concerns man's constant efforts to penetrate the mysteries of life and to understand nature; the practical objective is directed toward the improvement of our living conditions on this earth. Scientific research approaches both objectives at ever-increasing speed. The extent of scientific progress and the improvement in our standard of living and social structure in the past few hundred years as a result of the understanding of the laws of nature, have truly been amazing. Unfortunately, besides these highly beneficial, social implications of science, many negative implications follow or even precede progress—and these too occur with increasing speed. Indeed, science continually discloses not only many beneficial results, but also many others that are dangerous for mankind. Such results, when applied by the wrong people or in the wrong way, may disturb or even disrupt our social structure.

The obvious example of a scientific advance which constitutes a great achievement but which also has destructive social implications is the atomic bomb. The average person is convinced that this newest scientific discovery, the domestication of atomic energy, will be used mainly for destruction, although many scientists maintain that in the near future atomic energy will pay considerable social dividends to mankind. With the introduction of atomic warfare we have suddenly realized that the social implications of science are indeed very complex; today they have become more or less synonymous with disastrous consequences.

Another branch of science which will soon be contributing a further development with destructive social implications is bacteriology, the science of the minute organisms, billions of which live within and upon us. Many of these single-celled organisms are indispensable for the maintenance of our very lives, and others are our greatest enemies. In the past 80 or 90 years mankind has profited tremendously from research in the field of bacteriology, as is apparent from a few examples. Smallpox, which not so very long ago was one of the major calamities of the world and which all but destroyed entire populations, has been almost entirely eradicated since the introduction of universal vaccination. Malaria and yellow fever, both of which prohibited the settlement of many parts of the world and once were serious threats in our own South, have almost disappeared from many regions. Because of our victory over malaria, many subtropical and tropical regions are now habitable and have become important agricultural and industrial centers.

The most spectacular result of modern medicine is the prolongation of human life during the past 45 years. In 1900, life expectancy in the United States was only forty-nine years; in 1945, it had become sixty-six years. This great achievement has been made possible mainly through cooperation in the various fields of medicine, among which bacteriology and hygiene, a child of bacteriology, have been important. Yet in spite of its brilliant record of achievements, bacteriology is on its way to furnish, as has atomic energy, a means of mass destruction and thus a major threat to humanity. Along with atomic warfare, we are on the eve of bacterial warfare.

Atomic warfare has already demonstrated its potentialities, but bacterial warfare—that is, war using pathogenic bacteria as major weapons—has never been waged on a grand scale. We therefore can judge its practical importance and danger only from theoretical considerations and to a very large extent from our own imagination. During our nearly 100 years of bacteriologic research, however, many facts have been discovered which, in the opinion of many scientists, indicate that bacterial warfare, when properly developed, can become a weapon of scope and potentiality comparable only to the weapons of atomic warfare. There are, on the contrary, other scientists who disagree with this opinion and who do not believe that bacterial

warfare will ever become a practical weapon. Let us hope that we shall never have to decide who is correct—the optimist or the pessimist.

The concept of global bacterial warfare is of very recent date. It was first discussed in the European literature in the late nineteen twenties—about 10 years before World War II started, and it is not surprising that the first articles appeared principally in the French medical literature. At that time it became clear to many that sooner or later Germany would initiate another war. Since the Germans had always prepared for each of their wars with the greatest scientific precision and for each of their wars had invented new and more powerful weapons, the French were fearful that this time they would become victims of new devices, perhaps of bacterial weapons. Actually, Germany never used bacterial weapons, but this is no reason to assume that she did not have them.

In these earlier French articles bacterial warfare was clearly defined and many theoretical possibilities discussed. In the meantime, systematic research, especially in this country, has been directed toward the problem of bacterial war, and much specific knowledge has been collected. Many vague ideas, opinions, and theories have taken definitive shape in the past 10 years.

Bacterial warfare, as with atomic warfare, was a secret military or government project in all combatant nations during the last war, and it still is; so far, very little factual material has been released. This discussion on bacterial warfare, therefore, is based solely on my personal opinion and on published material available to everyone.

The weapons of bacterial warfare are pathogenic, that is, disease-producing bacteria or other agents of infectious diseases not only of man, but also of animals and plants. Included in this category are the toxic products, or toxins, of these bacteria and certain synthetic plant poisons, especially plant hormones and their derivatives. All these microorganisms or poisonous substances are employed for the sole purpose of producing diseases that will incapacitate human beings or useful animals, or destroy or damage food crops and other useful plants. In bacterial warfare we make subservient microorganisms that in their own natural way have waged war against mankind; we master them in the same way we have harnessed the electricity which, before Edison, razed our buildings, forests, and crops.

Although the microbial armies that attack man, animals, or plants are composed of microscopic organisms, their small size is compensated by their astronomical numbers and their great virulence. The effectiveness of any war weapon is measured in terms of its energy and destructive power. The explosion of an atomic bomb liberates fantastic amounts of energy; it produces millions of degrees of heat. Its destructive power can be measured by the extent of the demolition of Hiroshima or Nagasaki. But how great is the potential energy and destructive power of the biologic weapon, the bacterium or the virus? We know that certain bacilli cause diseases such as pneumonia, septicemia, tuberculosis, plague, cholera, and others and that they are capable of destroying our lives along with those of animals and plants. The magnitude of the power of microorganisms can be estimated by the epidemics and pandemics they bring about.

Let us illustrate this power with a few examples. Influenza is caused by a specific virus—a very minute microorganism. Influenza epidemics of varying intensities occur almost every winter, but every 30 or 40 years this disease assumes tremendous and catastrophic proportions. Many of us recall the great influenza pandemic of 1918–19, which probably had its start in an army training camp near Boston and which twice encircled the globe, missing only two small islands. This epidemic overtook 700,000,000 people, of whom 20,000,000 died. Within the fall months of 1918, the flu had killed more victims than died in the 4 years of World War I, in all armies put together. Few of us realize that the influenza epidemic of 1918 ranks with the Justinian Plague of the sixth century and the famous Black Death of the fourteenth century as one of the three most costly wars that microorganisms have waged against the human race.

The most impressive of all epidemics in history was the Black Death of the fourteenth century. This was an epidemic of plague, an acute infectious disease caused by the plague bacillus, carried by fleas that transfer the bacilli from rats to man. Plague occurs in two forms: the pneumonic plague, a pneumonialike disease; and the bubonic plague, the principal symptoms of which are inflammation and suppuration of the various lymph nodes. The course of both forms is extremely rapid and the mortality very high. Death occurs within three to five days.

The Black Death came to Europe from India or China, where it had been endemic for centuries, causing in these two countries, year after year, a constant but not too-alarming number of infections, with a relatively low percentage of deaths. The population of these regions had become immunized by the constant presence of the disease. When the plague spread for the first time to Europe, it found

an entirely fertile terrain among the unimmunized and highly susceptible population. To speak in terms of war, plague fell upon an unprepared and untrained population. The mantle of Black Death first enveloped Europe in 1348; two thirds of the entire population were afflicted and almost all died. Exhausted for lack of victims, the disease smoldered endemically for 12 years until a new crop of victims had grown up. In 1361, in 1371, and again in 1382 the plague flared up, and by the time it finally died out in Europe it had destroyed one fourth of the population—at least 25,000,000 souls. In later centuries the plague returned many times to many countries, in 1665 destroying 100,000 people in England, 200,000 in Brandenburg, and 300,000 in Austria in 1711. More recently the plague waged its battle in India, where it killed in the 40 years between 1896 and 1936 more than 12,000,000 persons.

The Black Death was one of the greatest shocks mankind ever experienced. A few economists believe that the modern world has not yet completely recovered from the profound sociological changes produced by this epidemic. We have many accounts of the plague by eyewitnesses. One of them is De Chauliac, a famous surgeon of Montpellier, France, who, referring to the plague of 1348 in Avignon, wrote:

> The great pestilence was so contagious that men died without attendants and were buried without priests. The father did not visit his son, nor the son his father. Charity was dead and hope crushed. The plague was great because it covered the entire world and left scarcely a fourth-part of the people.

Another epidemic disease that has battled mankind in well-characterized campaigns is cholera. As a world disease, cholera seems to belong to the nineteenth century. In six separate epidemics it attacked various countries of Europe, and about 270,000 victims perished. In 1947, there was a new outbreak of cholera, thus far confined to Egypt, with 8,000 cases and about 3,500 deaths as of the end of 1947.

There have been many other famous epidemics, such as, for example, the English Sweat, which prevailed in England, France, and Germany during the sixteenth century, or the syphilis outbreak, which came to Europe in the sixteenth century as an acute, widespread epidemic.

For many years the causes of all these great epidemics remained mysteries, and it was only toward the end of the nineteenth century that bacteriologists discovered the bacilli responsible for epidemics, and hygienists explained their spread. In spite of intensive studies and world-wide research in epidemiology, many factors are still unknown, the study of which constitutes major problems in sanitation and hygiene. The penetration of the mysteries of the sudden outbreaks of a mass infection and of the development of epidemics and pandemics is not only an important task for the hygienist, who watches over the health of the whole population, but is one of the most basic problems of bacterial warfare. Should anyone consider the use of bacteria as weapons and the production at will of a mass infection, he must be familiar with all the facts governing the onset, spread, and extinction of epidemics. He must be able to master the epidemic, to guide it, to foresee its course, and to delimit its field of action. It is no small wonder that epidemiologists are among the key personnel in the research on bacterial warfare.

One of the mysteries of epidemics is what the French refer to as the *génie épidémique,* the soul of the epidemic. Many of the bacteria capable of causing infectious diseases and epidemics are ubiquitous. They are found everywhere—around us, on us, and even within us. The influenza virus, for instance, is present normally in the nasal passages of about 60 percent of all persons. Many of us are carriers of meningococci and pneumococci, or we harbor hemolytic streptococci in our bodies. In spite of this fact, "carriers" are quite healthy and epidemics do not develop.

Similarly, plague bacilli have been found occasionally in rats or in fleas infesting rats in certain large cities. A few years ago a small, circumscribed plague endemic, which soon subsided, was reported from Paris. Sporadic cases of typhus are constantly reported in this and many other countries, and yet no major epidemic of typhus arises. That major epidemics do not always result is not because our hygienic measures are so nearly perfect (although this certainly is a major factor), but mostly because the *génie épidémique,* the ensemble of the specific conditions necessary for the onset and persistence of an epidemic, is not at hand—the environment, time, or the climatic conditions are not propitious.

Indeed, many factors must simultaneously collaborate to bring about and nourish an epidemic. One very important factor favoring certain epidemics is the lack of resistance of the population, that is, an increase in their susceptibility to infections. The general resistance of the population is, for example, lowered during the winter months, and it is a current observation that flu or diphtheria epidemics often have their start in January, February, or March. Great heat and humidity, rain, and cold are other atmospheric conditions that de-

crease resistance and favor the development of diseases in any given community. The economic conditions of a population often facilitate (or check) the development of certain epidemics; plague, for instance, is a disease of poor and undernourished people living in squalor. One of the most important factors favoring the spread of many infections is the disruption of good hygiene.

Our understanding of bacterial warfare can be greatly facilitated by recognizing that many of the important factors favoring the onset and spread of any epidemic are fulfilled during wars. In these periods, personal and general hygiene are at a low level, and great masses of military personnel and civilians are concentrated in besieged cities or in regions to which they have fled from the enemy. Their housing is bad, food supplies are rapidly depleted, famines are common, and the general resistance of the population vanishes.

No wonder, then, that epidemics are automatically the companions of wars. One can say that in the past the story of war was not so much a tale of the destruction of life or property by bullets and fire as the story of epidemics and disease that followed in the wake of the armies like a great shadow. In many wars, epidemics and disease have accounted for more destruction than actual warfare, and very often it was not the sword or the guns that decided the outcome of a battle or a campaign, but disease.

The forward march of Roman power was interrupted by the only force that was capable of opposing its mighty legions—the great Justinian Plague of the sixth century, which lasted fifty years and which, like its successor, the Black Death, felled about one fourth of the world population.

Another historical period of war epidemics is that of the Crusades, the story of which reads like the chronicle of an uninterrupted series of epidemics, pestilences, and famines. When, in 1098, the Christian army of 300,000 men besieged Antioch, disease killed so many and in such short time that the dead could not be buried. In the few weeks between September and November, 100,000 died; the victims were principally women and children who had accompanied the soldiers.

One of the most destructive wars of history, accompanied by famine, disease, and epidemics, especially among the civilian population, was the Thirty Years' War that from 1618 to 1648 ravaged Germany, Austria, Bohemia, the Netherlands, and parts of France. Armies from the various countries invariably carried epidemics from one place to another, and, wherever they appeared, one quarter of the civil population died. Like the story of the Crusades, the story of the Thirty Years' War is one long tale of panic-stricken populations fleeing the approaching armies in wild despair and dying from disease rather than at the hands of murdering soldiers. The population of Bohemia fell from 3,000,000 to 780,000, and that of Germany from 16,000,000 to 4,000,000—all this following, within 300 years, the plague that had itself destroyed as many lives and blighted the existing civilization.

The records for North America are no better. In 1520 when the Spaniards came to Mexico, one of the Negro slaves accompanying the army transmitted smallpox to the Mexican Indians. Within a few years more than 3,000,000 Indians died of smallpox, and the once mighty Aztec population was reduced to a small group of shaken beggars.

The American Civil War was one of the most murderous in history. Of 850,000 soldiers engaged in this war, 350,000 died; that is, more than 40 percent. But only 100,000 of them died from battle wounds; more than twice this number (60 percent of all who perished) died of diseases such as typhus fever, dysentery, and malaria.

I have mentioned some of the gruesome details of epidemics, and especially their dependence upon wars, in order to make two points clear: That we know of no greater destructive force on this earth directed against human life than that of pathogenic microorganisms, and that there are no better opportunities for pathogenic microorganisms to thrive and to start widespread epidemics than those presented by wars.

It is most surprising that only a very few attempts have been made to produce deliberately, in wartime, epidemics or infectious diseases in the camps of the enemy with the intention of weakening the adversary. During the siege of Caffa in 1346, the year when the Black Death first smote Europe, the plague broke out among the invading Tartars. The besiegers are said to have infected their foe by throwing over the walls, by means of engines of bombardment, corpses of persons who had died from plague.

Much later, in 1763, the English General Amherst, Governor of Nova Scotia, tried to destroy the Indians with smallpox by means of infected blankets. In 1917 the Germans are said to have tried to contaminate army horses in France with glanders. And, finally, Wickham Steed has reported that in 1940, in a certain part of China, the Japanese dumped from airplanes rice kernels contaminated with plague bacilli, with the intention of producing a plague epidemic there, far behind the lines.

As in the times of the Tartars, so may modern warriors consider the spread of infections behind the lines of the enemy as one of their principal objectives. But, in contrast to the crude attempts of the Tartars, in modern bacteriologic warfare we no longer need rely upon the uncontrolled spread of disease. Modern bacteriologic warfare strives for two well-controlled effects which govern the use of any weapon: optimal efficiency against the enemy and maximal protection of one's own army and civilian population. Consequently, the study of bacterial warfare is concerned with a number of major problems: the selection and mass cultivation of the most suitable microorganisms, or the mass preparation of toxins; the investigation of natural and artificial epidemiologic conditions; the technology of the bacterial weapon; and the protection of one's own army and civilian population.

Upon careful consideration of the conditions by which the various great epidemics develop, it seems quite possible that one could produce certain of these epidemics at will either in the ranks of the enemy army or among his civilian population. But it is also probable that it would be very difficult under most circumstances to control the spread of many artificially induced human epidemics. They would threaten not only the enemy's army and civilian population, but also those of the aggressor. For this reason none of the authors who have written about bacterial warfare considers as useful for such purposes the classic microorganisms of plague or cholera bacilli, flu or typhus virus, which have produced the great epidemics in the past, in peace as well as in war. I personally share this opinion and believe that a regard for the security of its own army and civilian population may prevent any responsible nation from making use of these microorganisms except in remote jungles or on islands. But the bacteriologist knows of other pathogenic microorganisms that so far have not produced epidemics of widespread character. It may be quite possible to deliberately produce with these germs incapacitating mass infections that might not spread by themselves and that would not endanger the aggressor's army.

The practical use of these organisms is possible since we are able to disperse and unload upon the enemy infectious microorganisms in such huge quantities that the resulting epidemics will no longer follow the pattern and the laws governing the spread of normal epidemics. Man-made artificial conditions may change the epidemiology of any disease in such a way that germs which hitherto have not produced large epidemics become useful war weapons.

Bacteriologic warfare—and this is the contribution of the modern age of biologic war—creates its own conditions for the dangerous spread of various diseases; it does not rely on the natural pathways taken by the classical epidemics, that is, spread by means of water droplets, by contact with infected material, or through diseased animals or foods.

Fortunately for us, many technical problems complicate the realization of bacterial warfare and may prevent its practical application, or at least render it more difficult. Many organisms, theoretically useful for bacterial warfare, are difficult to cultivate; in other cases, the bacterial preparations are either unstable or cannot retain their virulence over a sufficient period of time. Furthermore, certain microorganisms are unable to produce infections directly but require vectors such as insects, which in themselves are difficult to handle and which impose additional problems. Nevertheless, the principal difficulties with bacterial warfare are not these technicalities alone nor the problem of its power and impact. There is no question regarding the efficacy of many bacterial weapons; the real problem is that of self-protection.

Protecting the troops of the aggressor nation and its civilian population in the rear is of major importance. The soldiers who personally handle the propagation and dissemination of dangerous microorganisms can be protected to a certain extent by means of special uniforms or masks. But such mechanical protection is not feasible for all individuals in the army and civilian population, and other means are necessary.

One may consider prophylactic chemotherapy as being similar to malaria prophylaxis with quinine, or syphilis prophylaxis with bismuth therapy. Other preventive agents against infections are specific sera or vaccines; chemotherapy and antisera have the same importance for bacteriologic warfare as has the gas mask for chemical warfare. Treatment with antiserum and vaccine produces immunity, that is, protection from those microorganisms against which the serum or vaccine are directed. We possess excellent chemotherapeutic agents and antisera for certain diseases, but not for all. Antisera are highly specific in that they are effective only against certain pathogenic microorganisms and do not confer immunity against all other pathogenic microbes.

Unfortunately, we know of many infectious diseases in which immunization with specific sera or vaccines has had little or no beneficial effect. This applies especially to many infections which otherwise would lend themselves well to bacterial warfare. But even specific antisera do not give pro-

tection under all circumstances. Treatment with the best serum becomes useless should the enemy succeed in cultivating an antigenic variant of a pathogenic microbe, or detect a new virulent microbe against which no antiserum exists. Bacterial warfare is much more versatile than atomic warfare.

Considering the pros and cons of the various infectious diseases of man, there can be no doubt that the number of organisms that can be used effectively and safely in bacterial warfare aginst humans is greatly restricted. This, however, does not exclude the possibility, or even the probability, that bacterial warfare directed against human life may be used in certain phases of future wars. Whatever the scope and the effectiveness of such future attempts may be, whether or not they will be as colossal and dangerous as the effects of atomic bombs, one fact stands out: The human imagination, the fear of disease, or the feeling of helplessness will create much terror and despair. Demoralization may be even more important than the actual number of diseased persons.

Besides attacks against human beings, bacterial warfare is also concerned with the destruction of the enemy's livestock. Since epidemics of animal diseases generally follow the same pattern as human epidemics, many considerations already discussed also apply to them. The destruction of the enemy's livestock would exert a tremendous influence on the outcome of any war, since it would jeopardize the entire food supply. It must therefore be recognized that bacterial warfare directed against animals may constitute a serious threat. Properly conducted, such bacterial warfare may be highly effective over large areas; an example is the extent to which epidemics of foot-and-mouth disease may spread. The practical effectiveness of warfare against domesticated animals may be limited because of the relative slowness of the spread of many animal epidemics. For this reason, the destruction of useful animals probably cannot be considered as a general or major weapon, but it may be a helpful adjuvant.

Another aspect of bacteriological warfare is the destruction of useful plants. The potential extent of this type of biologic destruction is very wide, at least as broad as that affecting human life and animals. Moreover, it is more practical and has a less odious and emotional connotation. Each of our cultivated plants is threatened by one or more specific diseases that in peacetime often totally destroy a crop. Besides insects, there are many varieties of molds, bacilli, and viruses, all of which specifically attack and destroy the fruits, leaves, or roots of many crop plants, producing wilts, rusts, rots, blights, and smuts of fruits, vegetables, and grains. It is possible to cultivate many of the microorganisms causing these plant diseases, just as we do those microorganisms afflicting man or animals, and we can contaminate entire fields experimentally and deliberately.

The economic importance of the destruction of a wheat or a potato crop, for instance, is self-evident, especially if an enemy population is dependent entirely upon home-grown crops. The danger of spread from field to field can be greatly diminished by proper prophylactic treatment of the plants, and this danger of contagion does not exist when chemical substances rather than living organisms are used for the destruction of crops. Although the use of chemicals as weapons belongs to the realm of chemical warfare, certain plant-destroying substances are generally included in any discussion of biologic warfare. Chemicals have been developed which rapidly destroy many plants. An example of a plant poison is the new weed-killer, 2,4-D, which, incidentally, is a useful by-product of the research on bacteriologic warfare. Without question, bacterial warfare waged against useful plants is a type of biologic war that has the fewest pitfalls. It is the least dangerous for the aggressor, but very effective against the victims. Plants can be rapidly destroyed over large areas, with immediate results.

Thus far this discussion has dealt only with the naturally occurring epidemics, the possibility of deliberately producing epidemics in man, animals, and plants, and the difficulties encountered in the proper choice of a bacteriologic weapon. Several other technical problems should be mentioned, together with an analysis of certain differences between bacterial and atomic warfare.

Atomic warfare is a very complicated, elaborate, and costly enterprise, and only those nations endowed with great industrial and technical resources can produce atomic bombs. Bacterial warfare, on the contrary, is a cheap and comparatively simple method of warfare. It can be developed by any nation, large or small, rich or poor, to which the methods of modern bacteriology are available. One might truthfully say that bacteriologic warfare is the poor nation's atomic bomb.

Any bacteriology laboratory, whether in a hospital, research institute, university, industrial plant, or in a properly equipped private laboratory, can produce huge amounts of the bacteriological weapons. The equipment to cultivate and prepare bacilli is simple, and hundreds of liters of most powerful bacilli or virus suspensions are easily prepared. For instance, a simply prepared suspension

of the dangerous psittacosis virus, which produces a very serious pneumonialike disease, contains a million deadly human doses in a single drop; in other words, one drop properly dispersed is theoretically capable of killing a million people, and, consequently, half a cup of such a preparation could, again theoretically, eradicate all mankind. Equally simple of preparation are the "bacterial bombs," the containers and missiles in which the infectious material can be delivered to the enemy.

There is no comparison between the technology of bacterial warfare and that of an atomic bomb or any other modern weapon. Complicated devices are not necessary to transport "bacterial energy;" a cargo of microorganisms can be carried by plane, balloon, rocket, in a suitcase, or even in the pockets of spies and agents behind the enemy lines. Drinking water and food supplies can be contaminated from small bottles or vials; planes can spray the prepared cultures exactly as they now spray insect-killing chemicals over truck farms or infested woodlands. The microorganisms can be disseminated as artificial rain, or dispersed in exploding shells.

It may be true that bacterial warfare is not just around the corner; nevertheless, there is no choice but to accept, for general guidance, the statement recently made in an official Anglo-American government release that the possibility of bacteriologic warfare cannot be discounted. It is certain that any responsible government would refrain from using some of the possible bacterial weapons; but we must anticipate those irresponsible war lords and madmen, who, before their final defeat, and *in extremis,* throw overboard all conventions, treaties, and moral considerations. Might not a future Hitler or Mussolini try to draw his conquerors and even his associates with him into a cataclysm of deliberately produced pandemics of psittacosis or plague? It is, therefore, our first and most urgent task to prevent and control bacterial warfare just as eagerly as we try to prevent atomic warfare.

There can be no question of any unilateral action, as there can be no question of the unilateral control of atomic warfare. Recently, David Lilienthal, Chairman of the Atomic Energy Committee, wrote:

> The Atomic Energy Commission is today designing, developing and producing weapons of unimaginably destructive power. It is the firm resolve of the Atomic Energy Committee to maintain pre-eminence in these weapons until effective international safeguards are in force.

Similar considerations apply to bacterial warfare. It would certainly be unwise to neglect the development of its technological possibilities and the defenses against it.

Simultaneously with the intensive research and development of bacterial warfare that is now going on, we must arrive at an international agreement. Actually, bacterial warfare, together with chemical warfare, was condemned by a convention signed in Geneva in 1927 and ratified by eight nations. Many never believed that such a convention had any more practical value than similar previous conventions which failed to prevent the use of newly discovered weapons. In the thirteenth century the Lateran Council forbade the use of the arbalest, or crossbow. In the fifteenth century Bayard, in France, asked the interdiction of the use of the shotgun. Only recently—on February 9, 1948—Pope Pius XII, calling the atomic bomb the most terrible arm which the human mind has thus far conceived (his predecessor, 700 years ago, used the same term for the crossbow), urged that the use of atomic energy for warlike purposes be outlawed. All these interdictions have been without effect, since man has always used, and will use again, those agents of warfare that have proved to be most powerful and most efficacious. It is useless to outlaw arms or to discuss their legitimacy. Pascal realistically stated, "Since it was not possible to make strong everything which is legitimate, one has arranged to make legitimate that which is strong." If bacterial warfare can prove its strength, then bacterial warfare will be declared legitimate. It is not likely, therefore, that condemnations and interdictions will solve the problem of this type of warfare.

Any control of atomic, as well as of bacterial, warfare must start with manufacturing. In the manufacture of atomic bombs, the weakest link is the production of the explosive ingredient, plutonium. Unlike the atomic-energy plants, bacteriology laboratories are normal components of modern research and are easily established; this is precisely what renders any control of bacterial warfare so utterly difficult. Bacteriology laboratories can easily and unnoticeably be converted to noncivilian activity. Moreover, there are no major weak links in the production of the weapons of bacterial warfare; the necessary cultures and containers can be produced in small rooms anywhere, and it would therefore be necessary to maintain a spy system of dictatorial dimensions. One could perhaps consider the control of the vectors, or carriers, of bacterial warfare, the balloons, the guided missiles, and even airplanes. Eliminating these vectors would be an effective precaution, but who would or could now renounce airplanes? I personally do not see any other way than to resort to, and rely upon, political agreements.

POPULATION PHENOMENA AND COMMON KNOWLEDGE

LAMONT C. COLE*

Dr. Cole (Ph.D., Chicago, 1944) served during World War II as an officer in the U. S. Public Health Service, where he studied populations of rodents and their ectoparasites in relation to typhus epidemiology. For the past two years Dr. Cole has taught ecology and entomology at Indiana University. This fall he went to Cornell University as assistant professor of zoology.

ALL organisms as we know them, as they are available for present-day study, have behind them a long record of survival both as individuals and as types. Thus the diagnosis of the conditions determining survival, and of those which have determined survival in the past, becomes a central theme of ecology—the study of the interrelationships between living organisms and their total environment, both living and inorganic.

Part of the environment of any organism consists of other organisms, and when we examine interrelationships within a group of individuals belonging to a single species, we quickly become aware that the population has essential properties, not visible in the individual organism, which may tip the scale between survival and failure to survive. So far as the individuals are concerned, they compete with each other for food, space, and other essentials that are available in limited quantities, they may cooperate in exploiting their surroundings or in defense, and they are altered physiologically and behaviorally by propinquity. These and similar interactions may increase or decrease the probability of individual survival, and an immense amount of research has been devoted to evaluating these effects.

A slightly different emphasis is obtained by examining the properties of populations as these affect, not mere individual survival, but the survival of types of organisms. This long-time survival implies that the organisms are equipped for effective and certain reproduction. If individual reproductive success is uncertain, as it necessarily must always be, survival depends upon maintaining a sufficiently large breeding stock that adequate reproduction of the population approaches statistical certainty. The failure of one generation may mean extinction, a fate which has overtaken countless species known only from the geological record, but one which every living type of organism has somehow managed to avoid.

The emergencies that have been met and overcome by their ancestors during the long struggle for survival have left impressions on all modern organisms in the form of adaptive characteristics for increased efficiency in coping with their environments. Random variations that reduce efficiency have been eliminated and so have specialized adaptations to niches (opportunities for special ways of life) which at some time in the earth's varied history have ceased to exist. Similarly, the luxury of maintaining inefficient populations has been suppressed.

Our understanding of population phenomena has made impressive gains both in the field and in the laboratory following the development of new techniques to supplement the ordinary physiological methods suitable for studying individual survival. Outstanding among techniques for population study are the statistical approach, the selection of populations amenable to laboratory study under approximately natural conditions, and the formulation of theoretical mathematical models to deal with the subtle, unusual, and slow-acting environmental factors which exert their influence over the course of many generations. Studies employing these techniques continue to reveal new and ever more essential relationships between the population phenomena of growth, composition, organization, size limitation, and mass physiology on the one hand and population survival on the other.

As more or less a by-product of analytical population studies, there has emerged a great deal of information with a potential bearing on human welfare. Specialists have translated some of this information into practice in the population fields of demography, epidemiology, agriculture, game management, and pest control, but, unfortunately, common knowledge, as revealed by the popular press, seems scarcely to have advanced beyond

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LOW REPRODUCTIVE POTENTIAL

THE EXTINCT PASSENGER PIGEON PROBABLY PRODUCED ONLY ONE EGG PER BROOD; HENCE SURVIVAL DEMANDED A LARGE BREEDING STOCK AND A SOMEWHAT EXTENDED INDIVIDUAL LIFE EXPECTANCY.

blind acceptance of uncritical and often irresponsible statements by various vocal but uninformed persons or groups.

Experience shows that there is a type of man, common in all nations, who will hasten to support any environmental manipulation which, on grounds however slender, is proposed for improvement of those populations represented by his lawn, his favorite game animal, or his favorite stock of fish. He will, without asking why, join in the persecution of nearly any predator, whether it be a spider, house centipede, snake, hawk, or coyote; and, if control is effective, he may then attempt to personally substitute for the absent predator. He is easily alarmed by what is told him regarding human populations. He may join controversies over birth control, believing that an increased birth rate is the answer to all his country's problems while at the same time he is concerned over a shortage of food and *Lebensraum*. He is shocked if the death rate in his community begins to approach the birth rate and he is edified by someone's remark that a "normal" human life span should approximate one hundred and twenty years.

Until the average nonscientist can be brought to think critically and skeptically about loose statements of population problems and phenomena, there seems little hope of incorporating the potentially useful results of modern research into common knowledge. Many of the things which the public must learn to disbelieve scarcely require experimental demonstration. A little logic and some skepticism toward dogmatic generalizations coupled with a very little empirical information can clear the way for an understanding of the complex which ecologists are seeking to unravel. Thus, in the interests of common knowledge I shall attempt in the following paragraphs to clarify some of the simpler but most abused conceptions of population phenomena.

Some of the common fallacies about populations may be resolved by simply remembering that any population must be finite in size. The reproductive potentialities of all organisms are such that, if unimpeded, populations would grow in a manner very like a sum of money placed at compound interest. It has been estimated by Hodge that one pair of houseflies reproducing at their maximum rate could in five months produce enough descendants to cover the earth to a depth of 47 feet. By a slight extension of the computation it may be shown that under the postulated conditions about one year would suffice to make the number of houseflies equal to the number of electrons estimated by astronomers to be present in the visible universe. This is a dramatic but not an extreme case, as many organisms exceed houseflies in reproductive potential.

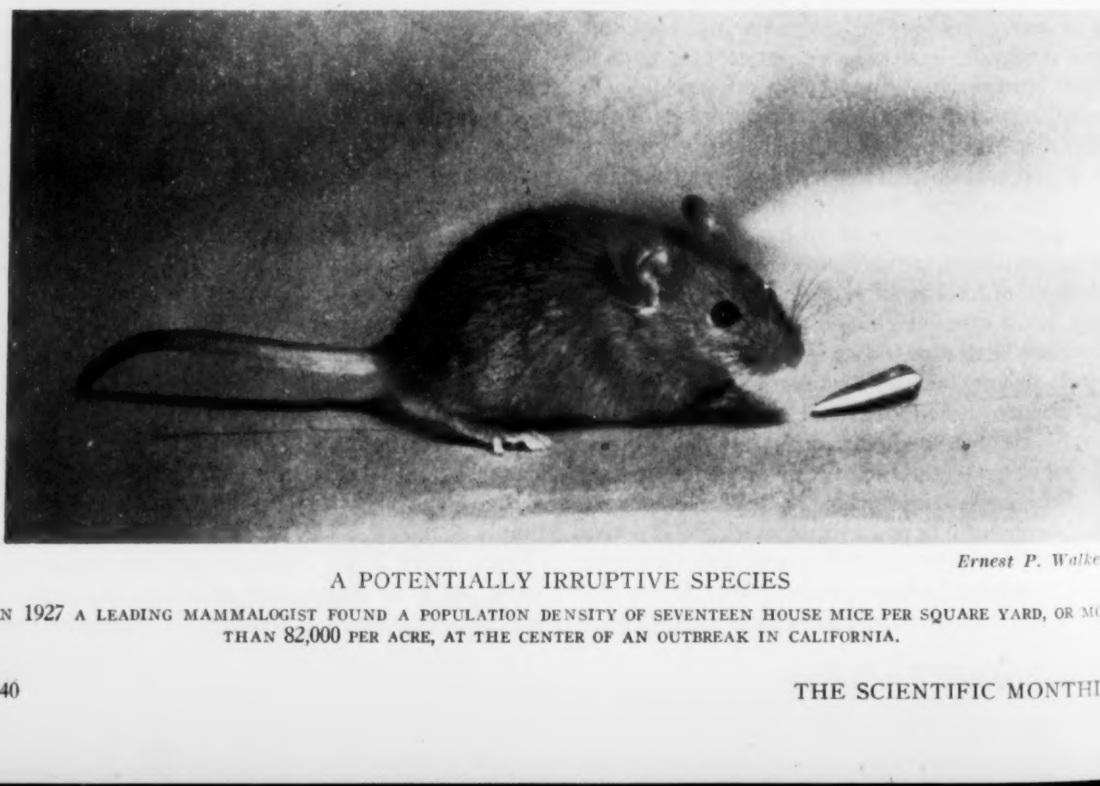
Any species in which two individuals, at the time of their deaths, consistently left behind more than exactly two offspring like themselves would grow at compound interest and, if unchecked, would eventually overflow the earth. Obviously, then, population increase cannot be indefinitely continued, and indefinite decrease clearly leads to extinction. Consequently, at some intermediate size all populations must attain an equilibrium where they neither grow nor shrink. The population may either remain at this stable level or may fluctuate about this level as an average. Sometimes such fluctuations are extreme, and the upward part of the cycle, in the form of "mouse plagues," "locust plagues," and "deer irruptions," attracts great attention. The point to be noted here, however, is simply that under any set of environmental conditions, there is for each species and population some stable or average equilibrium size toward which the population is trending. A population that

is growing or shrinking is in a temporary and unstable state. If we wish to understand population phenomena we must consider the population in its equilibrium condition.

If we consider a population which has attained a constant stable level in equilibrium with its environment, it is obvious that for each individual entering the population exactly one individual must leave. For a cyclically fluctuating population this condition will pertain over a long-time average, whereas for an absolutely constant population it will be true at all times. Additions to the population can come only from birth and immigration, and losses come only from death and emigration. For a generalized population picture we may consider a closed population or an entire species where changes result only from births and deaths and not from migration. Migratory movements do not change the basic population picture but merely obscure the vital statistics by counting a single individual as a birth with no corresponding death in one population and as a death with no corresponding birth in another. This, of course, tends to alter the birth and death rates recorded for the two populations without altering the average rate or in any way upsetting the correspondence of births and deaths if a larger group is considered.

Thus we see that in any population that has passed its temporary stage of growth and attained a stable condition there must be exactly one death for every birth, and, accordingly: birth rate = death rate. This could not be otherwise because all organisms are mortal and each one that is born must die. (Throughout this discussion we shall neglect the situation in organisms which reproduce solely by fission.) Any imbalance between birth rates and death rates can only be maintained while a population is changing in size in a particular direction and this, of course, is a temporary condition. Perhaps this seems too obvious to be worthy of mention, but the fact is that very many persons never view what they read and hear in this light. One constantly encounters references to communities and regions in which the human birth rate exceeds the death rate, presented with the implication that such a condition indicates a particularly healthful environment or even especially good medical care! Actually, there are only two possible interpretations of the situation; either the local population is in a temporary state of growth, or many individuals born in the locality move away to die elsewhere. The only permanent way of reducing the death rate is to reduce the birth rate.

It is usual for death rates to increase with increasing age. Therefore, a rapidly growing population where births exceed deaths tends to have a high frequency of young individuals, whereas, with the slowing of population growth, a shift is noted in the direction of increased average age and increased frequency of older individuals. Anyone can observe this shift in age structure by following the history of a particular population such as a growth of timber or the human population of the United States, but many persons fail to recognize



Ernest P. Walker

A POTENTIALLY IRRUPTIVE SPECIES

IN 1927 A LEADING MAMMALOGIST FOUND A POPULATION DENSITY OF SEVENTEEN HOUSE MICE PER SQUARE YARD, OR MORE THAN 82,000 PER ACRE, AT THE CENTER OF AN OUTBREAK IN CALIFORNIA.

its significance. When man is systematically exploiting a population, as for example in the fisheries industry, a shift toward increased age is a warning that reproduction has fallen below its maximum, whereas in pest control such a shift may be an encouraging sign that control is becoming effective.

The responses and behavior of a population are greatly influenced by the fact that it is not homogeneous but ordinarily consists of several types of individuals differing in their biological importance. In general, the number of females limits population reproduction and survival to a more significant extent than does the number of males. It is this fact that makes it possible to annually remove large numbers of male deer or pheasants (which are promiscuous, or at least polygamous) from a range without appreciable effect on the next year's production of young. Because this is true, it is not surprising that in their struggle for survival many animals have increased their reproductive potential by various mechanisms which make the most of the limited supply of environmental necessities available to females. Bee colonies may kill off excess males when food is short; female spiders frequently eat their mates after their eggs are fertilized; various mollusks maintain extremely unequal sex ratios by the teleologically beautiful expedient of having the excess males turn into females; and aphids and water fleas (Cladocera) which expand their populations rapidly in summer dispense with males entirely at this time, the summer generations of young all developing from unfertilized eggs and all becoming females. Parthenogenesis is the usual type of reproduction for many types of animals, and males of some species of insects have never been found, this sex apparently having entirely disappeared.

In addition to sex heterogeneity, most populations are divisible into about three age groups, which differ in population significance. The life span of many animals falls into three distinct periods: an immature or prereproductive period of growth and development, a period of potential reproduction, and a postreproductive period of sterility. The relative lengths of these periods vary greatly for different animals and may even be highly variable within a single species. The postreproductive period does not exist for May flies, salmon, and certain butterflies, which die immediately following reproduction; it amounts to some 50 percent of the usual life span in brown rats; and in populations of the Western mosquito fish

THE CLADOCERA, OR WATER FLEA

SHOWN HERE WITH YOUNG DEVELOPING IN THE BROOD POUCH, THIS FLEA DISPENSES WITH THE MALE SEX WHEN ENVIRONMENTAL CONDITIONS ARE FAVORABLE.

recently described by Krumholz it varied with the season of maturity, amounting to some 20 percent of the life span of overwintering females and to about 55 percent for those passing their entire life span in a single summer. For human females in the United States, the reproductive period effectively extends from about age fifteen to about age forty (97.43 percent of the births recorded in the U. S. for 1943 were to mothers aged fifteen to thirty-nine). Thus in man the postreproductive period makes up something over 25 percent of the usual life span.

The capacity of a population to increase at any given moment is clearly dependent not only upon total population size and individual reproductive potential but also upon the number of individuals in the reproductive period of life, which in turn depends upon population size and length of the reproductive period relative to the other parts of the life span. Any cause of death or sterility which removes individuals from the reproductive portion of the population means fewer births and a decrease in the reproductive and growth potentials unless the population can in some way compensate for the loss. Direct compensation leading to immediate expansion of the reproductive class has been suggested for rat populations where the in-

creased food and perhaps shelter made available result in earlier maturity and a longer span of reproductive life. However, such direct loss compensation achieved by altering the relative lengths of the reproductive and sterile portions of the life span is probably of much less general importance than the more delayed compensatory trends resulting from larger litters, more frequent reproduction, and, above all, increased survival of offspring.

The chief significance of the immature or prereproductive portion of the population stems from the fact that (barring immigration) this class is the only source of new reproductive individuals. Increased deaths in this group may produce a misleading apparent rise in birth rates because population size is decreased with no immediate loss of population fecundity. This, of course, is only temporary. Any decrease in the number of immatures means an eventual decrease in the number of reproductives unless compensation occurs in the form of increased individual reproductive performance or, as is common, improved survival of the remaining prereproductive individuals.

From the foregoing, it should be evident that the size of the prereproductive part of the population tends to be a simple multiple of the size of the reproductive class. Any permanent change in the relative sizes of the two classes presupposes that the population can be kept permanently in a condition of rapid growth (a possibility to be discussed later) or that the relative length of time spent by each individual in the two classes can be altered. Changes in the birth rate or differential mortality in the two groups can produce only temporary changes in the balance unless such changes are extreme enough to lead to extinction. For most species the relative lengths of the developmental and reproductive stages of life seem to be fixed and beyond human control. This points to a common fallacy of thought about population problems. In man the ages for physical labor and military efficiency correspond closely to the ages for reproduction, and it has often been proposed to expand this portion of a national population by tampering with the birth rates. It is no accident that such proposals are most frequent in countries that are already worrying about overpopulation—where the decreased rate of population growth has shifted the age structure in the direction of increased age. The fallacy of such proposals lies in neglecting the necessary corollaries of an increased birth rate: a general population increase in all three age classes and/or an increased death rate.

Losses from the postreproductive portion of a population are unique in biological significance. Such losses reduce population size without altering its fecundity and hence lead to an increase in population growth rate with a corresponding shift toward a youthful age structure. A dictator willing to risk the obvious consequences might eventually succeed in enlarging his armies by taking steps to reduce the number of postreproductives, but the matter is unworthy of discussion in connection with the control of human populations. It is, however, a very important subject in the management of game and commercial organisms.

By harvesting postreproductives, additional food, space, and other limited necessities are made available to the reproductive and potentially reproductive individuals. Also, the average reproductive rate per member of the population is increased, with a consequent more rapid production of individuals in all three age classes. Thus, the selective catching of the oldest fish in a population, which are also likely to be the largest and least fecund fish, has a positive stimulating effect on the growth of all age classes and also frequently reduces a mortality pressure resulting from cannibalism. It has been suggested and denied that predators serve a valuable function in nature by selectively removing the aged, unhealthy, and therefore most accessible members of prey populations, thus maintaining a progressive population structure.

Selective mortality of the postreproductives, with death rate accelerating with age, is a common phenomenon among organisms under usual conditions, and this serves as a natural control which maintains population fecundity by not allowing too large a proportion to slip over into the postreproductive class. In the case of man a shift to older population structure is reflected by new emphases in medicine and public health as the causes of death such as cancer and cardiovascular conditions, which are highly selective for older individuals, naturally gain increased prominence.

We now hear frequent comments on the extent to which human longevity has been increased and we are made aware that the search for controls for cancer and heart disease is in full swing. Without deprecating any of these efforts it may be well to glance at human longevity from the population standpoint to anticipate the effects of gains in this phase of medicine. We may first note that the effective maximum span of human life is somewhere near one hundred years and has changed very little if at all in historic times. If we compare United States life tables for 1941 with those for 1858, we find that in this period a newborn child

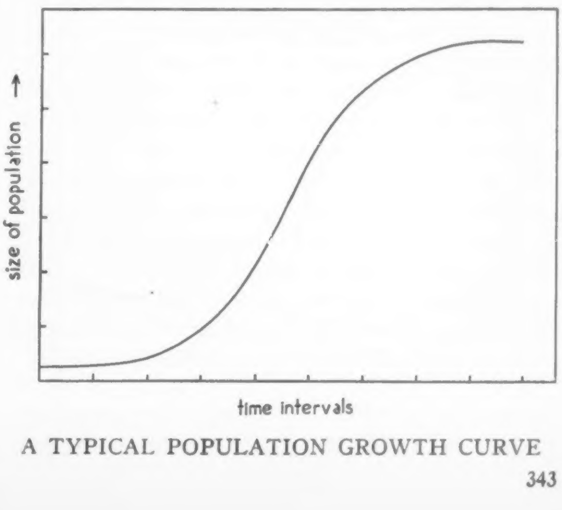
has gained in life expectancy by some twenty-two years, whereas a person of sixty can expect to live less than two years longer than his 1858 counterpart. The gains in longevity have come through increased survival in early life and not through lengthening of the life span. If the life span were to be much increased, it would necessarily mean that eventually a much lower proportion of the population would fall into the reproductive age class and that some new problems would have to be met. With lower death rates a smaller reproductive class might adequately supply the number of births necessary to maintain the population; but if man is going to continue heavy physical labor and warfare under such conditions, human vigor will have to be greatly extended into later ages.

If a few reproductive organisms are transported into a favorable and unoccupied environment and there begin building up a population, this population will, as already noted, tend to grow after the manner of money placed at compound interest. If we make a graph plotting the size of such a population against time, we find that, like money at compound interest, the rate of growth is at first slow but that it accelerates with time. This cannot be indefinitely continued, however. Sooner or later the rate of growth begins to taper off as food or space or some other resource of the environment is not produced rapidly enough to support the accelerated population growth. As the population continues to grow, it then grows more slowly until finally growth practically ceases and the population tends to remain at a rather constant level as long as environmental conditions are unchanged. The history of population growth thus describes a rough S-shaped ("sigmoid") curve. This type of growth is very general, and curves of this shape have been found to fit such diverse material as the growth in weight of vegetables, the number of victims of a communicable disease ("growth of an epidemic"), the growth of amount of lumber in woodlands, and the growth of populations of an extremely wide variety of organisms from bacteria to man. The sigmoid shape of the growth curve is usual no matter in what units the population is measured. For example, in fish populations a sigmoid growth curve is obtained whether the population is measured in numbers of individuals or in pounds of fish per acre of water surface.

A great deal is now known which enables us to rationalize the shape of the growth curve and a great deal is known about its mathematical properties, although some slight controversy still exists regarding the best-fitting mathematical model. For our present purposes it is enough that we merely accept the empirically established sigmoid shape of the curve, at the same time noting that the damping off of growth rate indicates some inadequacy of the environment to further support an increasing growth rate or an indefinitely large population.

Regarding this limitation of growth rate by limited environmental resources, many common misunderstandings might be noted. Perhaps the most common is the tacit assumption that limitation is brought about by inadequate reproductive potential. The construction of game-fish and game-bird hatcheries and other expensive means of adding additional immature members to a population should be undertaken only when the need for enhanced fecundity has been indicated by much more critical study than has usually preceded such endeavors.

If one traces the shape of the growth curve, paying attention to the rate at which the curve is rising for each unit of time, it will be noted that the maximum rate of growth and the maximum increase in number of individuals occur at some intermediate population size, with slower increase being characteristic of both large and small populations. This is the crux of a fundamental problem of population management which has come to be widely known as the "optimum-yield problem." If few individuals are removed from a population per unit time, the population remains large and adds new individuals slowly. If the rate of harvest is increased, the smaller population responds by increasing more rapidly; behaving exactly as if the population were returned to a previous state, moving further to the left on the curve in the figure. Thus by "fishing" harder and catching more "fish," you induce the population to produce fish more



A TYPICAL POPULATION GROWTH CURVE

rapidly. If one could know enough about a population to keep it at the size corresponding to the most rapid rise in the growth curve, one would then obtain the optimum yield, the largest possible sustained harvest from the population. Note, however, that any harvest greater than the optimum yield pushes the population back into a size range where it grows more slowly. If a constant rate of harvest were maintained under such conditions, the population would be progressively decimated and finally exterminated; but this seldom happens because the effort required to reap the last of the crop becomes prohibitive. When a commercially valuable population has been pushed back to this state, increased efforts to harvest a crop yield progressively diminishing returns. Regarding the situation in overexploited fish populations, Graham has written as follows: "All of the data lead to the same conclusion—that a certain proportion of the time and money of the fishermen is at present devoted to reducing their catch—or is at least wasted." Statements like the above appear anomalous to the average nonecologist and fisherman. It is extremely hard to explain that if he will fish less, he will catch more fish. Here again it seems that man might profit if a little more of known population phenomena could become a part of common knowledge.

There is another aspect of the optimum-yield problem. Efforts to remove pests by killing are often very like harvesting a population for commercial purposes. A rat population, for example, responds very rapidly to reduction of numbers by increasing the production of rats. Thus a sustained yield on a high level may be obtained without appreciably abating the rat problem. It would doubtless be a very impressive figure if one could collect information as to the total annual expenditure in the United States which goes to increase the harvest of "pests." Of course, a sufficiently vigorous and sustained campaign could push the population back beyond its level of maximum growth rate and make it possible thereafter to keep it at a low level without undue effort, but this is not the usual result of our antipest programs.

A similar phenomenon becomes visible when one carefully scrutinizes the activities of the much-maligned and persecuted predatory animals. It has too long been accepted as self-evident that predation is deleterious to a population exposed to it, whereas a stronger case can be made for regarding predation in general as analogous to the yield phenomena described above. Reproductive potentials being what they are, almost all animals typically produce more offspring than can possibly survive. Ordinarily, a portion of the population entrenches itself and gains the use of the environmental resources while the surplus individuals are doomed to death whether by predation or some other factor. As with pest control, the predator reaps diminishing returns per unit effort as the prey population is pushed back into smaller size classes, and it is unusual for any animal other than man to exploit a population obliteratively. Predation reduces the size of the prey population, which responds by more rapid growth, increased survival of offspring, and increased individual reproductive performance—responses which in this connection are often called "intercompensation."

On the other side of the ledger, the value of predators for controlling noxious species has doubtless been overestimated in the popular mind. Predators are typically larger than their prey and, being larger, they typically have lower reproductive potentials. When, as happens in connection with population irruptions, the environmental situation is such that a population approximately achieves its potential rate of increase, it typically outbreeds any predators that may increase along with it in response to the unlimited food supply. When both predator and prey increase at compound interest, the prey species may ordinarily be expected to exhibit the higher rate of interest. The disparity between numbers of prey and predators thus becomes greater the longer the unimpeded increase continues. Under such circumstances, predation becomes effective in population control only after environmental resistance has retarded the growth rate of the prey population.

A great many additional examples of known population phenomena which merit a place in common knowledge might be presented. Nonecologists are generally aware of the deleterious effects of overpopulation but generally unaware that underpopulation may be as deleterious, or even more so. Population size has important influences on the course of evolution, populations (at least of vertebrates) frequently exhibit internal structure on the basis of social dominance and/or the defense of individual territories, populations may differ in breeding structure with consequent differences in their potentialities, and they may exhibit extreme degrees of division of labor between individuals so that whole populations survive or perish according to the efficiency of particular classes of individuals.

Finally, populations of different species interact with unilateral or mutual benefit to produce larger systems, which stand in relationship to the popu-

lation about as that unit does to the individual organism. These larger units are a dominant part of the environment of man (a part often referred to mystically as "the balance of nature"). They are complex and they are relatively new as objects of serious investigation. However, with the background information now available on the populations which are the building stones of these larger associations, ecological knowledge is advancing rapidly. Man will benefit when sound information on populations becomes a part of general knowledge; sometime in the future sound knowledge of biotic communities will aid man in improving his relationship to his own environment.

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U. S. Forest

OUR FORESTS AND WATERSHEDS

EDWARD N. MUNNS

Mr. Munns, a University of Michigan graduate, began his career as first assistant on Angeles National Forest. After World War I he did forest research throughout the California region of the Forest Service. Later he was transferred to Washington, D. C., and put in charge of silvicultural research. He is now Chief of the Division of Forest Influences, U. S. Department of Agriculture, which includes the forestry phases of watershed surveys under flood control legislation.

MAN can live without shelter or clothing for months, or at least with improvised makeshifts; he can live without food for days; but life without water is measured in hours. Water is the most vital physical resource of a community. Among all the natural forces basic to our economy, its behavior is one of the most obscure. The product of climate, it is closely related to the soil and its cover, and it has for thousands of years affected the life of man and the evolution of his civilization.

Hydrology, strangely enough, cannot be considered by itself, but must always be related to the land—to climate, to soil, to vegetation. Solomon and the philosophers of ancient Greece explained that springs were fed by subterranean channels from the sea. Even during the Middle Ages this idea persisted. It was not until around 1650 that it was learned that the amount of water in the streams was related to the rainfall of the catchment basin. From then on, the relation of water to the land became more and more apparent, and as time went on it was realized that water could not be studied without taking into account land as well. Various advances were made in the next two centuries. The source of artesian water was discovered, a way was found to measure the velocity of streams, and, finally, it was learned that soils and rock may be permeable.

The natural processes involved in the hydrologic cycle are complex. Some, like evaporation and transpiration, cannot be measured accurately; others, like deep seepage, cannot be measured at all. Man does know, however, that there has developed a harmonious adjustment of the physical forces that relate to vegetation, soil, and water. Consequently, as our knowledge of the behavior of water increases, especially in its relation to vegetative life, we shall be able to exert a perceptible influence on the water regimen.

It has long been known that good forests, good soils, and good water go hand in hand. Contrariwise, when man uses the land improperly and seriously upsets the ecological balance between soil, water, and vegetation, a reaction sets in which may be disastrous to civilization. Thus, fire following logging on steep mountain slopes invites erosion; erosion reduces the rate at which water can enter the soil; water that cannot enter the soil must run off; an excessive amount of surface runoff means flashier streams and an increasing number of floods—one reason why these appear with sickening monotony in all parts of the United States.

So far the cause-and-effect relations of various kinds of land use and water are not too clearly established. Although in the past quarter century many valuable records of the amount of water carried in the various streams of the country have been compiled, these data cannot be related to the complex watershed conditions over a large drainage area. Consequently, they do not tell us much about the effects of any specific type of land use on the water resource. To get a clear picture of such relations, records from small watershed units are required, where the influence of land clearing, timber cutting, grazing, tillage, etc. can be closely observed.

The United States Forest Service is particularly concerned with discovering the principles of beneficial watershed management, since it is responsible for the protection and administration of many important watershed and headwater areas. For a number of years, the Forest Service has been carrying on investigations in the rela-

COWEETA EXPERIMENTAL FOREST

TWO PANORAMIC VIEWS OF U. S. FOREST SERVICE EXPERIMENTAL AREA NEAR FRANKLIN, NORTH CAROLINA. A TREATED AREA FACES THE CAMERA JUST ABOVE AND TO THE RIGHT OF THE HEADQUARTERS BUILDINGS.

tions of forests and water in outdoor laboratories scattered throughout the United States. One of its major laboratories is the Coweeta Experimental Forest, in the Nantahala Mountains of western North Carolina, about 80 miles southwest of Asheville. Here, in an area of 5,400 acres, are conditions highly suitable for hydrologic research.

The Coweeta area lies in a zone of heavy rainfall. Precipitation averages 65–90 inches a year and comes from many storms—sometimes 100 a year—of all kinds, heavy, light, intense, very gentle. Although no one year's rainfall pattern is exactly like another, there is enough comparability in the storms and their distribution to permit collection of an abundance of data in a relatively short span of years. This area was selected as a hydrologic laboratory for other reasons also. The geology is uncomplicated, and the topography is particularly suited to watershed observations. Lying at elevations of 2,200–5,200 feet, the deeply weathered Archean rock gives rise to a wonderfully deep and well-drained soil. The slopes are steep, and the sharp-crested ridges form natural boundaries for the many small watersheds into which the Coweeta Forest is divided. Each experimental watershed is a miniature valley, complete within itself, and ranging from 20 to 200 acres.

Cover conditions on the Coweeta Creek watershed are excellent. A dense mixed hardwood forest is dominant, with scattered pines only on old fields or on the ridge tops at lower elevations. Although about 60 percent of the area had been cut over a quarter century or more before the Federal government acquired ownership, this part of the Coweeta now supports a second-growth forest, with the remainder still in old growth. Before being killed out by the blight, chestnut was the major species. Now about 80 percent of the Experimental Forest supports oak-hickory stands, 15 percent cove hardwoods (yellow poplar, northern red oak, hemlock), 5 percent Northern hardwoods (sugar maple, yellow birch, beech), and conifers. The forest is three-storied: large trees form an upper layer, small trees the second, and shrubs or herbs cover the ground.

In the Southeastern states rapid industrial growth and the expansion of many cities have created a rising demand for water supplies. Ground waters are believed to be progressively decreasing, and stream flow is becoming less uniform and dependable, while the quality of surface water drawn on for domestic use and industrial processes is deteriorating because of sediment and pollution.

We may well ask, To what extent is this situation due to land conditions, and what can be done to improve and conserve water as a basic resource? Specifically, what types of land use are most favorable to water resource conservation? Are we managing our municipal and industrial watersheds so as to obtain the maximum quality and quantity of water? These are the questions to which the Forest Service is attempting to find answers at Coweeta.

The long-range plan of research is directed toward four related fields:

1. To establish fundamental forest and water relations.
2. To furnish coefficients of runoff, infiltration, and water storage for different types of land use such as grazing, logging, and "mountain farming."
3. To develop principles for silvicultural management that will provide for maximum supplies of usable water of highest quality.
4. To work out feasible and practical methods of stabilizing the soil in logging operations, on road banks, and along streams and reservoir shore lines.

Up to now, the investigations have been mainly concerned with the first two fields.

At present, the water behavior of 28 watersheds is being studied. Of these, 16 are being treated experimentally and 12 are held as control units and for future experimentation. On each watershed hydrologic measurements are taken by self-recording instruments, so that the amount and intensity of the rainfall in each watershed can be synchronized with stream behavior at the gauging station, with changes in the level of the ground-water table in observation wells, and with temperature, evaporation, and other climatic factors. Soil-moisture determinations are made periodically. Water temperatures and turbidity data are also taken.

The behavior of ground water is being studied by means of observation wells in which movements of the water table are recorded by automatic instruments. These records have demonstrated that water tables close to the surface may be quite sensitive to individual storms throughout the year, but deeper wells show significant replenishment normally during the late winter months.

Several treatments on different watersheds are being studied. It had been originally thought that a standardization period of ten or more years

CLEARING THE FOREST

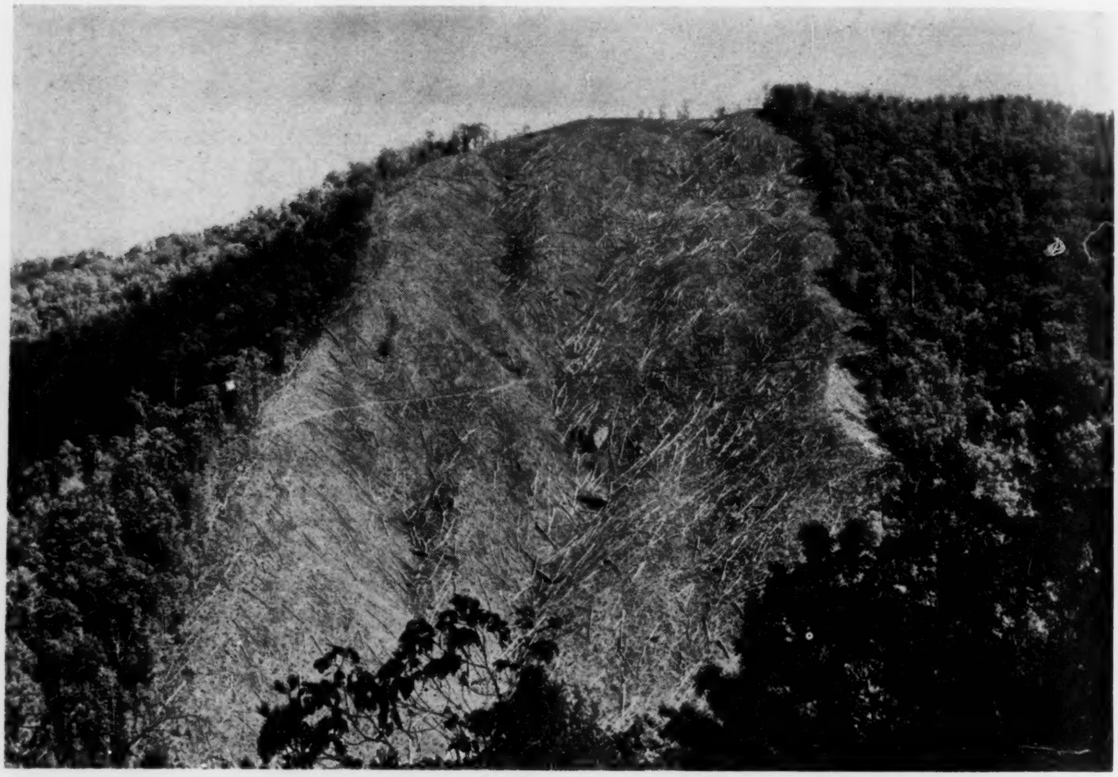
PART OF THE WATERSHED AREA IS TO BE TURNED INTO A TYPICAL "MOUNTAIN FARM." FENCE ON RIGHT MARKS BOUNDARY OF WATERSHED. GAUGING STATION IN FOREGROUND. LOWER VIEW SHOWS SAME AREA IN SPRING FOLLOWING CLEARING. UNCUT TREES IN BACKGROUND INDICATE CHARACTER OF FOREST BEFORE CLEARING. RAIN GAUGES, GROUND-WATER WELLS, AND SELF-RECORDING METEOROLOGICAL EQUIPMENT ARE IN PLACE.

U. S. Forest Service

would be required before any treatment could be applied. It was soon discovered, however, that because of the pattern of precipitation and the large number of storms per year the stream behavior was fairly uniform basin by basin, storm by storm, and season by season. This, plus the areas used as a check, permitted investigators to compare each treated stream with itself and so cut in half the time required for standardization.

The results of the treatments have thrown a good deal of light on how the vegetative cover influences the production of water as well as the behavior and rate of discharge in the streams. With this kind of information at hand, it may be possible to suggest land use practices to attain different goals—such as where flood control is the primary objective, where water yield is the main consideration, or where regularity of stream flow is chiefly desirable.

The first watershed studies carried out on the Coweeta dealt with the effects of temporary cutting of all major vegetation. On two small watersheds (33 and 40 acres), the trees and understory down to broomstick size were cut to the ground early in 1941. All the cut material was left where it fell in order not to disturb the litter and humus. Before cutting, sufficient stream flow and climatic records were obtained so that the normal relations between rainfall and runoff could be established. On one watershed, the trees were allowed to sprout up again as they would following a normal cutting operation. On the other, the sprouts were cut back each year so that they never attained any appreciable size. A similar drainage area was left uncut to serve as a control unit.



SMALL EXPERIMENTAL WATERSHED AT COWEETA

ALL FOREST GROWTH WAS CUT DOWN TO BROOM-HANDLE SIZE AND ALLOWED TO REMAIN WHERE IT FELL. SPROUTS HAVE BEEN KEPT CUT BACK TO THE GROUND SINCE, WITH NO DISTURBANCE. AS A RESULT, THERE IS A WEALTH OF FAUNA AND FLORA, AND THE SOIL IS EXCEEDINGLY POROUS AND OF A BEAUTIFUL CRUMBLIKE STRUCTURE.

On stream flow, the effect of removing the vegetation was spectacular. In the first year after cutting, the total runoff was increased by 17 area inches, or 65 percent, without any indication that storm flow was augmented or the quality of the water impaired. The largest augmentation of flow occurred in late summer and fall. On the watershed where the sprouts have been kept down, this phenomenon has been repeated each year. On the area where the regrowth of vegetation has been permitted, the higher water yields have persisted, al-

though becoming gradually smaller in amount.

On another basin of about 22 acres, only the riparian forest was cut. Again no disturbance of the forest soil was permitted. Here, though the cutting was limited to a narrow strip of trees with their feet in the ground water and amounting to only 12 percent of the drainage area, there was a 20 percent rise in stream flow. Again the quality of the water was unaffected.

Foresters have long tried to get a fairly definitive statistical answer to the question of what effect the customary logging and skidding practices have on the quantity and quality of the water yield in our mountainous regions.

To get logs from the tree stump to the sawmill is usually difficult and laborious. The logs must be skidded to a point where they can be taken out of the woods. In the Eastern hardwood forest, they are usually loaded on trucks and hauled over roads that wind through the woods. In building and using these skid trails and truck roads, a great deal of soil is normally disturbed—litter and even humus are destroyed—and conditions favorable to erosion are created. Here is a common source of watershed deterioration that results, among other things, in the muddying of streams and fish depopulation.

At Coweeta a 212-acre watershed was cut and logged in 1942–43 by a contractor who was permitted to use the methods common in the Southern mountains. He cut whatever trees he wanted and got them out of the woods in any manner that appealed to him. Logging was resumed in 1945. A 2.3-mile truck road was bulldozed into the area in a location chosen by the contractor. Most of the profitable trees have since been removed from this watershed.

TYPICAL ROAD CONSTRUCTION ON COWEETA EXPERIMENTAL FOREST

THIS IS THE TYPE USED BY LOGGERS GENERALLY THROUGHOUT THE EASTERN MOUNTAINS. ONE SMALL STRETCH OF ROAD SUCH AS THIS PROBABLY RESULTS IN THE DESTRUCTION OF MORE FISH IN A WEEK THAN ALL THE FISHERMEN IN A COUNTY COULD DESTROY IN A SEASON.

The effects of logging were soon perceptible in the quality of water flow, which deteriorated markedly. It was found that the logged watershed yielded an average turbidity of 95 parts per million, compared with 4 parts per million for the uncut control unit. The flow from the logged area ran as high as 6,000 parts per million in contrast to a maximum of 120 parts per million for the control unit. Moreover, the water from the logged water-

shed was always laden with debris and never met the standard of 10 parts per million set by municipalities for drinking water. In addition to these adverse results, the mud flowing into the stream indicated that erosion was occurring on the logged forest. Most of this originated on the skid trails and the poorly built and maintained truck road. Erosion continued even after logging was shut down. The full effect of logging on stream flow, as distinguished from water quality, has not been completely analyzed, but there are indications that the peak flow has been somewhat increased.

These results seem to bear out the conviction, based on observations in other parts of the country, that logging is a primary cause of erosion and sedimentation of mountain streams. So far, all the advances in logging methods have been for the benefit of the operator, not for that of the forest or of the water. Those involved in studying water problems believe that the efficient planning of a logging job will result in savings to the operator as well as to water users.

Perhaps the most interesting small drainage area in the Coweeta Experimental Forest is that cleared for agricultural use in 1941. It has long been thought that mountain farming is harmful to the watershed. The experiments at Coweeta have provided supporting data.

A local farmer was induced to operate the 23-acre mountain farm as he saw fit. Conforming to the local pattern, on the more gentle, 30 percent slopes he grew corn and on the steeper slopes grazed cattle. For the first two years there was an increase of water production on the cleared watershed without much damage to the quality. By the third year erosion was in progress; in fact, by then the organic material in the cornfield was largely gone and the structure of the soil was breaking down so that infiltration began to decrease. Surface runoff then occurred with every rain. The peak discharge hit a high of 398 cubic feet per second per square mile during the rain of July 30, 1943, compared with a recorded maximum of 48 cubic feet per second per square mile before clearing.

Erosion on the tilled area became so prevalent that the main creek was discolored for a considerable distance downstream. Thus, before clearing, the rate of sediment movement based on accumulation in the catchment basin was 9.4 pounds per day. After clearing, it shot up to an average of 767.6 pounds per day in the period May 4–September 8, 1943.

After two years of tillage no corn was planted, and the fields were allowed to grow up to natural weeds; many seedlings and sprouts of yellow poplar and locust became established. The sediment flow was decreased but still was four to five times the volume noted before the area had been cleared and farmed. Corn was again planted in 1946, but the yields fell off greatly. They were increased in 1947 with the application of fertilizer. The damage to the watershed, however, persisted.

Grazing on a 145-acre forested watershed also produced proof of the damage that livestock inflict upon the soil. Compaction was prominent wherever there was any nutritious forage, and the undergrowth of palatable tree seedlings was practically wiped out. The soil became less porous and hence less able to absorb and store water. With the loss of the understory, wind was able to get under the crowns of the tall trees and blow away the litter.

A drainage basin of 39 acres was selected for a fire experiment. This watershed had never been cleared but had been cut over many years prior to the time the land came into Federal ownership. A new forest of oaks and hickories had come in, covering the area uniformly. No sign of fire could be found in the area, even on the old holdover trees.

The experimental area was burned over on April 14, 1942. The blaze consumed about four fifths of the litter on the ground; most trees less than 4 inches in diameter were killed and branches below 14 feet scorched. The larger trees suffered considerable damage when sizable areas of the cambium layer were killed.

So far as the watershed was concerned, the results of this experiment were inconclusive. Stream flow was seemingly not affected because, as is normal at this elevation in the spring, the soil under the litter was quite moist; consequently, the blaze did not alter the structure nor affect biological activity in the soil. Soon after the burn, sprouts and new herbaceous growth appeared. These served to protect the soil from the impact of subsequent hard rains. Inspection revealed, however, that the soil had been dangerously exposed by the reduction of litter and humus and that repeated fires would create unfavorable conditions for the percolation and storage of ground water. This area will be burned again, and probably another area will be chosen for a fall fire.

What have the results of the watershed treatments at Coweeta added to our knowledge of the behavior of water and its relation to the forest?

First, we have gained much information about basic hydrology, particularly a more realistic in-

terpretation of forest and stream-flow relations in terms of watershed storage. It is now possible to explain the behavior of a stream on the basis of the source of its water; that is, (1) channel precipitation and overland storm runoff, (2) water detained in temporary subsurface channels, and (3) ground-water storage. As we have seen, different types of land use affect these three elements in varying measure.

Of especial significance from the standpoint of fundamental hydrology are the findings that relate to the balanced water economy of small watersheds. The results obtained substantiate the theory that in humid climates the precipitation recharge for any one year should tend to equal the discharge from the watershed in the form of runoff, transpiration, and evaporation, together with the changes in soil moisture and ground-water storage.

On the practical side, the Coweeta studies have suggested some of the measures to be used in beneficial watershed management. First, we have discovered that the mixed hardwood forest of the Appalachian area uses much more water, especially during the growing season, than had been suspected. Simply by removing the vegetation much more water became available for runoff. And, as long as the soil and litter mantle are not disturbed or dissipated, the additional water does not create flood hazards.

Second, Coweeta has demonstrated in a clear-cut fashion that any disturbance to the soil will change the watershed picture. Logging causes compacted skid trails, which become focal points for surface runoff and induce erosion. Livestock constantly trailing through the woods in search of forage tend to compact the soil and dissipate the leaf litter, thus stimulating quick runoff and attendant erosion.

PLOWING THE "MOUNTAIN FARM" WATERSHED AT COWEETA

The study of mountain agriculture showed that tillage rather quickly breaks down the structure of the soil. The crop yields tend to diminish as fertility declines unless large amounts of fertilizer are applied to the soil. The Forest Service plans to continue the farming of the tilled area at Coweeta until some kind of uniform runoff and erosion pattern is obtained, after which an effort will be made

to determine how long it takes to re-establish a good forest soil.

The Coweeta investigations also suggest that a dense forest of a type that uses a great deal of water may be highly desirable for flood control purposes. Thus the litter and humus permit maximum infiltration in the soil, and during the growing season the forest tends to use up a large part of the precipitation that comes in the form of heavy storms. By drying out the soil, the forest provides storage space for subsequent storms so that the soil goes into the winter relatively dry.

The high water use by a dense forest, on the other hand, suggests that we can increase the supply of water for man's purposes by cutting out the heavy water users. This kind of treatment could be recommended to communities and industries that wish to augment their water supply.

The Coweeta experiments have clearly demonstrated that timber cutting and grazing seem to cause more damage than is usually imagined. The increase in stream turbidity alone justifies the elimination of these practices on highly critical Appalachian watersheds.

Then, too, erosion from any cause results in sedimentation and in discoloration of the stream. As a result of the discoloration, water temperatures are increased and the amount of light reaching the bottom is decreased. Higher temperatures decrease the amount of oxygen in the stream. Both the higher temperatures and the decreased oxygen result in fish, especially trout, moving out or, under extreme conditions, dying. Decreased light and oxygen react unfavorably upon the aquatic life upon which fish feed, so that a stream may become sterile. Mud and sand settling on the bottom also bury fish food and, in the spawning period, may ruin the nest or smother the eggs. Thus abuse of watershed lands affects the fish population.

In the final analysis, the adverse effects on the water supply resulting from forest land use are due to indifference and carelessness. The experiments at Coweeta suggest that our water problems, though staggering in some regions and localities, can be solved and that forest lands can be managed in the interest of the water resource. Though many questions remain to be answered, Coweeta has, so to speak, opened the hydrologic door.

SOCIAL ASPECTS OF HOUSING

PAUL C. GLICK

Dr. Glick (Ph.D., Wisconsin, 1938) has been in charge of family statistics in the Population Division of the Bureau of the Census since 1940, except for the war period, when he was in the Research Branch, Information and Education Division, War Department. His article is the fourth in the series of sociological articles now appearing in* THE SCIENTIFIC MONTHLY.

THE first comprehensive inventory of housing in the United States was made by the Bureau of the Census in 1940. This census of housing provided information on the amount and quality of shelter in use or available for use by the American people. At the same time, this Bureau collected and tabulated the most detailed information ever obtained on charcteristics of the population of the nation. The results of the population census most directly related to housing are those on the number and types of persons who were living together as households. The facts established through the censuses of housing and population in 1940 have served as valuable bench marks with which sociologists and economists could compare the findings of current surveys made since that time.

In addition, historical series have been prepared by the Bureau of Labor Statistics on the number of new nonfarm dwelling units constructed in the United States and by the Bureau of the Census on the number and characteristics of households (household: a family or other group of persons, or a single person, occupying one dwelling unit). These series, extending back several decades, help to explain how the present housing situation has arisen. Furthermore, the series on number of households has been projected several years into the future, mainly on the basis of (*a*) the forecasts of population by age and sex prepared by the Bureau of the Census and the Scripps Foundation for Research in Population Problems, and (*b*) past trends in the tendency for persons of each age and sex to maintain a household. These projections have been widely used by analysts who were forecasting long-time needs in housing and in other fields where households are more appropriate units of measurement than persons. The Federal Reserve Board has also sponsored surveys of consumer finances on a nation-wide basis during 1946, 1947, and 1948, from which were obtained estimates of contemplated housing purchases during the year.

The number of dwelling units at a given time includes both occupied and vacant units. Thus, in April 1947, there were about 41.7 million dwelling units, of which 39.1 million were occupied and 2.6 million vacant.

Furthermore, within one household there may be more than one family group. In April 1947, for instance, there were about 39.1 million households, but at that time there were close to 4 million family groups (mostly married couples and parent-and-child groups) that were sharing the living quarters of someone else.

Trends in household growth and housing construction. During the 58 years since 1890 the increase in number of households, 221 percent, has been at a rate more than half again as high as the increase in population, 130 percent. The difference between these percentages of increase is a result of the factors that have caused the average size of household to decline sharply. Furthermore, the rate of household growth will continue to exceed the rate of population growth as long as the decline in household size continues (Table 1).

The lowering of the birth rate and the consequent decline in the number of young children living at home account largely for the diminution in size of household. The underlying reasons for the decline in the birth rate have been changing attitudes toward the value of having a large number of children, as our culture has been transformed from one that was predominantly agricultural to one that was predominantly nonagricultural and as standards of living have risen. A secondary factor that has generally been overlooked is the decline in death rates; more and more persons are surviving past the time when

*This article was not prepared in the official capacity of the author and should not be interpreted as representing official estimates of the Bureau of the Census.

their children have left home, thus leaving a larger proportion of small households comprising one or two elderly persons. A third factor that cannot now be documented is a possible tendency toward more widowed and older single persons maintaining households of their own rather than living with relatives.

TABLE 1

Population, Households, and Population Per Household, for the United States: 1890–1960

Census, Survey, or Forecast	Population (thousands)	Households (thousands)	Percentage Increase Since Preceding Census or Survey		Population per Household
			Population	Households	
1890[1]	62,948	12,690			4.9
1900[1]	75,995	15,964	20.7	25.8	4.8
1910[1]	91,972	20,556	21 0	26.9	4.5
1920[1]	105,711	24,352	14.9	20.2	4.3
1930[1]	122,775	29,905	16.1	22.8	4.1
1940[1]	131,669	34,949	7.2	16.9	3.8
1948[2]	145,085	40,720	10.2	16.5	3.6
1960[3]	159,909	45,100	10.2	10.8	3.5

[1] Decennial census.
[2] Sample survey of civilian population as of April 1948.
[3] Forecast for July 1960.

Another trend of central importance has been the cumulative difference between the net growth in number of households and the number of new dwelling units constructed. Figures for nonfarm areas in the United States for the period since 1930 are shown in Table 2. (Data on housing construction are not available for farm areas.) These figures show that the increase in nonfarm households during the 1930s was nearly 2 million greater than the number of new nonfarm dwelling units constructed. This difference is, in part, a consequence of the fact that the number of dwelling units built in the 1920s was greater than the increase in households by well over a million; but a considerable amount of the apparent excess in construction during the 1920s was absorbed by those who were short of housing in 1920. From 1940 to 1948 the number of new housing units constructed was less than the increase in households by another 1.8 million, making a difference of about 3.7 million for the period 1930–48. The latter figure is approximately one tenth of the 34 million nonfarm households in April 1948.

The main way by which the growth in number of households could thus have exceeded the number of new housing units constructed was more intensive use of previously existing living quarters. This more intensive use took such forms as the subdivision of units into a greater number of smaller units, the continued habitation of units that would ordinarily have dropped out of the housing market, and a sharp reduction in the number of vacant dwelling units. These types of adjustment to the current housing shortage will be discussed at greater length below. An additional factor, which probably explains only a small part of the excess in nonfarm household growth, is the continued use of units in the open country that were formerly classified as farm units but that are now classified as nonfarm units because agricultural operations are no longer carried out on the land.

Population growth. In settled times the greatest source of demand for new housing in this country is population growth. In such times, there is an increase each year in the number of households that desire and can afford separate housing space. During the 1940s, for instance, the expected increase in the number of households in the United States would have been about 500,000 per year if the employment level and the marriage rates had not been unusually high. Actually, during this decade the average annual increase in number of households will likely be half again the "normal" number.

During the 1950s, however, the expected increase in number of households on account of population growth is somewhat below 500,000 per year because the number of young people reaching the age for establishing new homes will reflect the low level of the birth rates during the 1930s. This source of housing demand during the 1950s could readily be more than offset, however,

TABLE 2

Net Increase in Number of Nonfarm Households and Number of New Nonfarm Dwelling Units Constructed, for the United States: 1930–48 (Numbers in thousands)

Period[1]	Net Increase in Number of Nonfarm Households		Number of New Nonfarm Dwelling Units Constructed		Difference	
	During Period	Cumulative	During Period	Cumulative	During Period	Cumulative
1930 to 1940	4,646	4,646	2,734	2,734	1,912	1,912
1940 to 1945	3,205	7,851	2,334	5,068	871	2,783
1945 to 1948	2,766	10,617	1,861	6,929	905	3,688

[1] For households, dates are as of midyear for 1930, 1940, and 1945 and April for 1948; for dwelling units, all dates are as of January 1.

by demand arising from the large number of families that are now inadequately housed.

Practice of sharing dwelling units. In addition to the normal growth in population, the practice of sharing other persons' living quarters by family groups that would prefer, and could pay for, separate quarters must be taken into account. In 1930 there were about 1.5 million married couples not maintaining their own households; most of these couples were members of relatives' households or were living as lodgers. By 1940 this figure had increased to nearly 2 million and by 1947 to nearly 3 million. By way of caution it should be noted that, on the basis of surveys of housing intentions conducted by the Bureau of the Census, it is known that a substantial proportion of married couples living with others do so voluntarily, for such reasons as financial inability to maintain a separate home and convenience in the care of young children or of aged persons. Yet the same surveys lead one to assume that about one half of the nearly 3 million couples not maintaining a home of their own constitute active housing demand.

In this connection mention should be made of the more than 1 million family groups, other than married couples, that were not maintaining separate households in 1947. A substantial majority of these groups consisted of parent-and-child groups, most of which were living with relatives. With few exceptions these groups were not financially independent and consequently did not constitute an important factor in the demand for new housing.

Practice of subdividing dwelling units. In addition to family groups that are known to be living temporarily with others only because suitable housing is not locally available, there is a large number of family groups who have chosen to live in small "converted" units because these quarters generally provide more privacy and the facilities for preparing meals at home. These units satisfy the criteria of separate households, but the occupants in many cases desire, and are financially capable of paying for, more adequate living space.

A converted structure is one that contains a larger or smaller number of housing units than the number for which it was originally built. The most common type of conversion is that of subdividing a structure into a greater number of smaller units, but in some cases, of course, the opposite process of combining two or more smaller units into one larger unit does take place. Many structures that have been converted had been built several years ago when families were much larger, on the average, than they are today. The units into which they have been divided often combine, therefore, the disagreeable features of cramped quarters and obsolescence. The decline in the lodger population since 1940 is indirect evidence that during recent years rooms or suites of rooms in many structures once used as lodging houses for unattached individuals have been equipped with plumbing and cooking equipment and rented as apartments. Furthermore, some structures not originally built for residential purposes have been converted into living quarters, but the number is probably inconsequential.

It would be unfair to leave the impression that all converted units are substandard; some of them provide ample and comfortable quarters for a small family group and therefore constitute a permanent addition to the supply of separate housing units. In many cases existing structures have been enlarged in order that each of the converted units might have adequate room. Moreover, once a household has supplemented its income by renting a part of its living quarters to another family, there is a reluctance to discontinue this additional source of income. But in so far as the current occupants of converted quarters desire and can afford more ample and modern quarters, they are a factor in the active housing market.

No attempt on a national scale to measure the net effect of "conversions" (units gained minus units lost) has been very satisfactory. An approximation of the net gain during recent years in number of dwelling units attributable to conversions can be made, however, by subtracting from the increase in the number of households the number of new dwelling units constructed and the amount by which the number of vacant dwelling units has decreased. A calculation of this type yields an estimate of about 1 million converted units added in nonfarm areas during the seven years between 1940 and 1947. Since the 1947 data are based on a sample survey, however, the estimate is subject to sampling variability. A similar calculation cannot be made from census data for the 1930–40 period because the 1930 census did not show the number of vacant units. However, an estimate of 2,392,000 nonfarm vacant units in 1930 was reported by M. H. Naigles, of the Bureau of Labor Statistics, in the April 1942 issue of the *Monthly Labor Review.* A comparison of this estimate with the 1,903,000 nonfarm vacant units as shown by the 1940 census indicates a decrease of about half a million in the number of vacancies in nonfarm areas between 1930 and 1940—a period when construction of new dwelling units fell nearly 2 mil-

lion below the increase in number of households. The same article contains an estimate of 1,060,000 units added by conversion (by remodeling of structures or in unremodeled housekeeping units) during the 1930s.

Continued use of substandard housing. Far more numerous than either the married couples living doubled up or the households living in converted units are the households living in substandard dwellings that are defective because they are temporary, dilapidated, hazardous, or too small. In the following paragraphs are presented averages of estimates, made by housing authorities in seven private and public agencies, of the number of substandard units in the United States today plus those units expected to enter this category during the next 10 or 15 years. The estimates of these and other authorities are presented in a report entitled *The Housing Situation—the Factual Background,* prepared by the Housing and Home Finance Agency for the National Conference on Family Life held in Washington, D. C., in May 1948.

Many of these estimates are for nonfarm areas only. One reason why estimates for farm areas are often neglected is the fact that measures by government to improve farm housing would be complicated by numerous administrative difficulties. The main type of housing needed in farm areas is new replacements for the most seriously substandard units in existence today, since population growth in farm areas is at a standstill. This type of need, however, is relatively great.

An average of the most conservative estimates made by the authorities referred to above who indicated needs for replacing substandard farm units was about 1.5 million. In addition, about 4.5 million dwelling units in nonfarm areas, again according to an average of the most conservative estimates presented by the authorities referred to above, are now substandard or are expected to become substandard during the 1960s. Where several estimates were given by one authority, the lowest one was selected. This was done because the higher estimates may not have taken full account of the possibilities of renovating many dwelling units that are now substandard. The progress already made during the 1940s in the reduction of the number of dwelling units with characteristics often used as indexes of substandard housing can be seen from the results of sample surveys conducted by the Bureau of the Census; many, if not most, of the authorities whose estimates were averaged in arriving at the above figures did not have the benefit of those results when they made their estimates. It should be emphasized, however, that the estimates of the number of substandard units just cited do not represent official estimates made by the Bureau of the Census.

Estimates of substandard housing naturally reflect opinions regarding what constitutes adequate ends toward which to aim. The estimates are correspondingly varied. Most people would probably agree that the average estimates represent worthy objectives for achievement by 1960, provided certain contingencies are met. The act of adding 6 million new dwelling units to the supply over and above the number needed to meet the basic needs arising from population growth, current doubling, and the current vacancy shortage, would require provisions for effective removal from the market, probably by demolition, of most of the units they were intended to replace. Although this and many other contingencies could probably be met if a sense of urgency in the matter were felt by those who would have to implement the program required to provide that much new housing, it is beyond the scope of this paper to speculate as to whether that sense of urgency will actually develop.

It is relevant, however, to point out a few of the criteria available for use in arriving at an estimate of substandard housing in the nation as a whole. Such criteria are listed in Table 3, together with the number and percentage of all dwelling units in the United States in the category in 1947, according to the results of a national sample survey conducted by the Bureau of the Census:

TABLE 3

Criterion	Number of dwelling units	Percent of all dwelling units
In need of major repairs	4,120,000	9.9
In need of major repairs or (in urban areas) lacking both private bath and flush toilet	6,070,000	14.6
With 1.51 or more persons per room	2,367,000	6.1
With 1 or more married couples sharing the living quarters of the head of the household	2,513,000	6.4
With rental under $20 (nonfarm tenant-occupied units only)	4,140,000	9.9

Of course there is a great deal of overlapping among dwelling units with the above characteristics, which can be demonstrated by the results of cross-classifications not shown here. Furthermore,

any one criterion taken alone would not be sufficient evidence that the unit should be replaced. Many units would be adequate if renovated, enlarged, or used by a smaller family. On the other hand, these criteria do not reveal the number of units with such other defects as being poorly lighted, too closely spaced, too far from one's place of employment, or situated in otherwise adverse environments.

A very promising method for evaluating the quality of housing in segments of a city of metropolitan area is described in an article by Allan A. Twichell in the June 1948 issue of the *American Sociological Review*. The method he presents was developed by the American Public Health Association and takes into account not only a series of measurable characteristics of the dwelling unit but also another series of quantifiable data regarding the environment in which the unit is located. By such an appraisal technique any single dwelling unit or any neighborhood of dwelling units can be placed at a point in the scale that includes all units surveyed. It probably would not be feasible, however, to make the necessary expenditure to obtain such data on a nation-wide basis.

Need for reasonable number of vacant units. Authorities in the field of housing maintain that 3-5 percent of the dwelling units should be vacant at a given time in order to permit free movement of families in their adjustment to changing needs for living space. The lower estimates are generally used when the types of vacancies referred to are restricted to effective vacancies, that is, vacancies that are for sale or rent and habitable throughout the year.

It should be emphasized that the total number of vacant dwelling units is usually in considerable excess of the number that is in the effective housing market. Thus, estimates based on a nationwide sample survey conducted by the Bureau of the Census indicate that, of the 2.5 million vacancies in 1947, only one out of every six was habitable, nonseasonal, and available for sale or rent. Only 1 percent of all dwelling units in 1947 were vacant and met these criteria, and four tenths of those vacancies were on farms. Thus, the quality and type, as well as the availability of vacant units to families in need of them, must be taken into account in appraising the vacancy situation.

The vacancy shortage in recent years has been aggravated by the widespread movement of the population. Only 44 percent of the heads of households in 1947 were still living in the same house they had occupied in 1940. There were sweeping migrations of people to distant war jobs, and relatively few of them returned after the war. Migration out of the South and to the West was especially heavy. The population of California increased 42 percent from 1940 to 1947. There were 37 percent fewer nonwhite households on farms in the South in 1947 than in 1940, and outside the South nonwhite households increased by 50 percent.

Because of the nature of these large-scale movements, an increasing proportion of the vacant dwelling units are on farms, and a decreasing proportion in urban areas where the demand for housing is far more intense. In addition, the population of metropolitan districts has for decades shown a continuing preference for dwellings in suburbs. This tendency has helped along the obsolescence of homes in downtown areas and kept vacancy rates low in suburbs.

To these observations we may add that nearly one half of the vacancies in 1947 were seasonal dwelling units, such as cottages in resort areas quite remote from places of employment, and one tenth were classified as uninhabitable. A substantial proportion of the remaining vacancies were assuredly substandard. The foregoing remarks should make it apparent that the consideration of local, as well as national, conditions is of utmost significance in a thorough analysis of vacancies.

If effective vacancies were defined as habitable, nonseasonal units for sale or rent, and if 3 percent of all dwelling units in urban areas of the United States as a whole in 1947 had been in the effective vacancy class, about 750,000 such vacancies would have been expected. Actually, the number was only about one fifth that large. Furthermore, if each housing market area taken separately —such as each metropolitan area—were to have an effective vacancy rate of 3 percent, the number of additional effective vacancies needed might well exceed 1 million. Furthermore, when the housing situation does improve and the number of vacancies increases, many of the vacancies coming into the effective housing market will be the substandard units that have been occupied only on a temporary basis during the most acute phases of the housing shortage.

Losses by demolitions, fires, floods, etc. This final factor to be discussed is relatively minor, since available estimates indicate that only about 40,000 dwelling units are lost per year by demolitions or catastrophes. If estimates of housing needs for a long period are being made, however, an item is generally entered for such losses. No allowance is made in this figure for large-scale demolition projects accompanying the replacement of substandard units.

In this paper the types of factual data available to sociologists and research workers in related disciplines for appraising the current housing situation have been presented. These data provide a basis for estimating the amount of additional housing needed immediately and in the long run to meet certain objectives. These needs and some of their implications may be briefly summarized as follows:

1. Persons who have made estimates of our housing requirements are in general agreement that housing construction on a scale exceeding that in our peak years (about 900,000 units) will have to be maintained for many years if the general level of housing conditions is to improve substantially. An average of the estimates of over-all housing needs, made by seven authorities referred to above in the discussion of substandard housing, is about 12 million nonfarm dwelling units and about 2 million new farm units needed between 1948 and 1960, with the estimates varying according to the degree of improvement visualized.

2. If 14 million new dwelling units were constructed during the next 12 years, provision could thereby be made for:

- 5 million units for households added through population growth;
- 1.5 million units for family groups now doubling up and seeking separate living quarters;
- 6 million replacements for occupied units that are now substandard (including substandard converted units) or that will become substandard during the period;
- 1 million increase in urban vacant units for sale or rent and habitable in all seasons; and
- 0.5 million normal replacements for units demolished or destroyed by fire, floods, etc.

3. How nearly such an objective will be attained depends on many contingencies relating to the maintenance of active housing demand. If employment levels remain high, if prices for housing construction fall to a more favorable level in relation to family incomes, if much more rental-type housing becomes available, and if most of the substandard units to be replaced are demolished or otherwise completely removed from the housing market, the demand for housing will probably remain high. The fact remains, however, that a significant proportion of the families in substandard housing units will undoubtedly be unable by their own means to provide standard housing for themselves. The extent to which such an objective as outlined above will actually be realized, therefore, will depend on economic and political forces that no one is in a position to forecast with confidence.

4. An objective appraisal of the current housing situation should include an acknowledgment that many aspects of the problem cannot be readily quantified. The physical structure of the house or apartment and the environmental setting might well pass all the statistical tests and still be undesirable living quarters for a particular family or unattached person in need of housing space. A vacant unit may be ruled out of consideration by the family because of the ethnic composition of the neighborhood; the unit may be unsuited to the needs of the family during its present phase of the family cycle; or the unit may be for sale only, whereas the family prefers to rent during the current phase of the business cycle. It would be very easy to extend this list of real but unmeasured factors. The existence of these problems, however, makes certain elements in the housing situation, such as the number of needed vacant units, most difficult to estimate with much accuracy.

5. The universal need for good housing in desirable neighborhoods has innumerable personal, family, community, and national implications. That social adjustments are conditioned to a large degree by the quality of housing is so well accepted that it need not be elaborated. Suffice it to say that substantial improvements in housing would reduce the irritations that arise out of living under crowded conditions and would also reduce the deterioration of physical and mental health that is often associated with living in hazardous and otherwise substandard structures. In short, improved housing would lay a foundation that would make the treatment of many social problems far more simple.

CHARLES BABBAGE: A SCIENTIFIC GADFLY

CHARLES F. MULLETT

Dr. Mullett (Ph.D., Columbia) has written extensively for scholarly journals on science, religion, and imperialism. After teaching in New York and Indiana, he went in 1925 to the University of Missouri, where he is still professor of history.

SCIENCE has had its heretics no less than religion. Some have disputed the basic premises; others, particular trends; still others have attacked those obstacles that restrict its potentialities. Such a one as this was Charles Babbage (1792–1871), whose frequent stinging assaults a century ago derived from the decline of science in England and the causes that gave rise to that decline. Had he stood alone, he would have deserved at most a footnote, but his convictions, if not his exasperation, were shared by many, laymen as well as eminent scientists.

The son of a banker, Babbage became one of the shrewdest mathematicians and most distinguished scientific mechanicians of his day. A sickly childhood and desultory education permitted him to indulge his "inveterate habit of contriving tools" and his passionate fondness for algebra, so that when he entered Trinity College, Cambridge, in 1811, he had already acquired a knowledge of the subject far beyond that of his tutors. With John Herschel (1792–1871) and George Peacock (1791–1858) he strongly preferred the Leibnitzian notation to the awkward Newtonian calculus, and the three founded the Analytical Society (1812), whose transactions Babbage would have published under the title "The Principles of pure D-ism in opposition to the Dot-age of the University." When, in 1816, the three translated the treatise on calculus, founded on Leibnitz, by the celebrated François Lacroix (1765–1843), Babbage also suggested periodical meetings for the propagation of *d*'s and the consigning to perdition of the *dot* heretics. He graduated B.A. from Peterhouse in 1814, and M.A. in 1817. Between 1815 and 1817 he presented three papers before the Royal Society, to which he was elected in 1816. In 1820 he produced some original work in Leibnitzian calculus and helped found the Astronomical Society; five years later he was at work on magnetism.

Meanwhile he had for years been working at the instrument that was to bring him his greatest fame, a calculating machine, much more complicated and valuable than earlier ones. Encouraged by the distinguished physicist William Wollaston (1766–1828), he had by 1819 made considerable progress. A small engine, contrived between 1820 and 1822, received high praise from many sources, and the government's interest prompted Babbage to work several years on the larger machine. Then misunderstandings over the work led to delay. During the interval Babbage evolved some new ideas, but the government did not respond, and it remained for others to apply the ideas he had ingeniously worked out. Nevertheless, in the opinion of those qualified to judge, the tools alone that Babbage had produced justified the government's expenditure of several thousand pounds.

During the same years Babbage engaged in other enterprises. While abroad in 1828 he got the materials that went into his most complete book, *On the Economy of Machinery and Manufactures* (1832, 4th ed., 1835), which was translated into four languages as well as reprinted in the United States. He shared extensively in the founding of the British Association for the Advancement of Science and the Statistical Society; he contested a parliamentary seat twice on the Whig ticket; he kept extensive workshops annexed to his house and produced some practical inventions; he was elected to many academies. All the while he carried on controversies that steadily bordered on the vituperative, whether the subject was street nuisances, the dereliction of the government, or the decline of science in England. To this last he contributed a full-length volume, *Reflections on the Decline of Science in England and on some of its causes* (1830), and chapters in his study of the economy of machinery and manufactures and in *The Exposition of 1851; or Views of the Industry, the Science, and the Government of England* (1851). No doubt he voiced the same views elsewhere, but the essential core can be found in these three.

According to the Preface of the *Reflections* Babbage was solely inspired by a desire to serve English science. In England few persons pursued science for itself. Moreover, although Continental scientists kept up with English discoveries, Englishmen were usually ignorant of Continental advances. Newspapers, magazines, reviews, and

pamphlets had attacked the conduct, officers, and publications of scientific societies, but these criticisms were regarded as personal and therefore dismissed, when they were really professional and might have done much good. In consequence England fell below not only its political equals but its political inferiors. To make the situation even more appalling, the country was everywhere distinguished for utilitarian ingenuity.

Although Babbage was registering his own convictions, the *Edinburgh Review* had anticipated him by a dozen years. In 1816, in reviewing the *Principles of Fluxions,* by Archdeacon William Dealtry, F.R.S. (1775–1847), it commented sharply on the state of science, particularly mathematics, in England. The defects of the book under review went far beyond its own specific shortcomings. They consisted not in teaching falsity but in not teaching what was known. By laying down only those principles necessary for its particular problems, the book conveyed the impression of completeness and mastery of all problems to which the calculus could be applied. Unfortunately, a student, even after having mastered this whole treatise, could not grasp the first six pages of Laplace's *Celestial Mechanics.* The author mentioned no new discoveries. He set forth nothing that had not been known a century ago; more than this, he did not even relate all that was known at that time. Foreigners were omitted, and Newton received only superficial treatment.

The deficiencies of the volume became forcibly apparent on comparison

> with any elementary treatise of the same size, and on the same subject, that has appeared within the last fifty years in France, Germany or Italy. The success which the work has nevertheless had, the rapidity with which it has arrived at a second edition, and the support it seems to have met with in the University where the mathematical science of this island is supposed to be concentrated, are abundant proofs, that, in the higher mathematics, we have not of late made the same progress as the neighbouring nations. It is certainly a curious problem with respect to national genius, whence it arises, that the country in Europe most generally acknowledged to abound in men of strong intellect and sound judgment, should, for the last 70 or 80 years, have been inferior to so many of its neighbours in the cultivation of the science which requires the greatest and most steady exertions of the understanding; and that this relaxation should immediately follow the period when the greatest of all mathematical discoveries had been made in that same country. This is a paradox not altogether impossible to be explained, and to the consideration of which, having no room at present for such a discussion, we shall be glad hereafter to return.

Three years later the *Edinburgh* did return to the subject. The reviewer of Robert Woodhouse's (1773–1827) *Elementary Treatise of Astronomy* noticed the great progress of physical astronomy on the Continent and the absence of the same in England. He found the explanation in the too-great reverence for Newton, which had kept back the introduction of the calculus into England. To know the advances of neighbors it was necessary to know their language, not of speech alone, but of science. Moreover, whereas in England people promoted general knowledge and neglected technical knowledge, in France they promoted both. Pensions and honors were heaped upon their discoverers, but in England the only reward was the opportunity to read a paper to the Royal Society, which itself had held out little encouragement to mathematical learning. Perhaps the *Edinburgh* might also have noted the long shadow of Newton: men were busy filling in his lacunae and too much in awe to enter where he had not trod. Not to be disregarded also were the inadequacy of university instruction, the devotion to utility, and the character, not merely of the Royal Society, but of so many learned or professional societies in England.

Babbage himself attacked the neglect of science in the educational system. Some improvement had taken place at Cambridge in the preceding fifteen years, but not much. A university degree ought, he said, to be the pledge of a certain quantity of knowledge; the progress of society warranted that the character of that knowledge would change. Degrees should be awarded only to honors students and should keep pace with the needs of society. To supply curricular deficiencies Babbage outlined four areas of concentration in three of which science formed the backbone: Modern History, Laws of England, Civil Law; Political Economy and the Applications of Science to Arts and Manufactures; Chemistry, Mineralogy, Geology; Zoology and Botany, each including Physiology and Anatomy. A student should take only a limited number of examinations, he thought, in order to distinguish himself in those he did take. By such means Babbage hoped to augment scientific knowledge.

He hoped also to increase the inducements to individuals to cultivate science and thus attract first-rate minds. Because the pursuit of science was not in England a profession, government and public alike failed to discriminate between original and hack researchers, and amateurs were often chosen for professional tasks. Fortunately, law, in attracting the highest talents, and medicine and divinity, in attracting good talents, had some powerful allies of science. Of political encouragement there was little, a lack justified by many on the grounds that the public was the better judge and that government rewards were smaller than business profits.

Long intervals elapsed between the discovery of new basic truths in science and their successful application. Men had constantly to remember that the mathematical truths of one generation formed the bases of profound physical inquiries in the next and were of practical use to all in the third. At the time of the first discoveries, however, existing apparatus did not permit their mechanical application.

For one original discovery there were many applications. One should reward the application, yes, but certainly not less the person capable of setting forth the original truth. Unless this were done, the contriver of some invention would alone derive substantial profit, whereas he on whom the invention basically depended went unrewarded to his tomb. Great discoveries did not emerge from the universities because professorships inadequately rewarded the "pure" scientist. Moreover, they entailed drudgery, a drudgery Galileo could escape but not John Dalton, who, incidentally, was eventually granted a government pension through Babbage's own plea.

The advance of science risked some danger from government interference—the ignorance of the judges, the indifference to qualified opinion, and the subservience of the qualified opinion itself. Such a situation had permitted wasteful expenditures on certain publications through ignorance or indifference. Hence government subsidies had to be carefully sought—and carefully spent. It was a commentary on the state of science in England that an English translation of Laplace's *Celestial Mechanics* had come from America. Be it remembered also that Laplace himself had dedicated his writings to "that extraordinary man" Napoleon, during whose reign "the triumphs were as Eminent in Science as they were splendid in arms." In Continental countries savants were well rewarded. Laplace (1749–1827), Carnot (1753–1823), Chaptal (1756–1832), and Cuvier (1769–1832) had all held high office in France; similarly, Prussia had honored the two Humboldts, Alexander (1769–1859) and F. W. (1767–1835); Modena had made Rangoni (1744–1815) its Academy president and minister of finance and public instruction; Tuscany and Saxony alike had rewarded well their eminent scientists. England herself had not always been indifferent, but now to suggest an appointment such as Newton's at the Mint would have brought only smiles.

Learned societies, which should be the font of scientific rewards, were often remiss. At one time they had been a practical necessity, especially in the matter of supplying apparatus, and they had otherwise stimulated research. Election to them should be a distinction, but in England that was scarcely the case, in comparison with several other countries. France, with a population one third larger than that of England, elected only 75 members to its distinguished academy; Prussia and Italy, with populations only slightly more than half as large as England's, elected 38 and 40 members; but England elected 685 members to the Royal Society. Where one Englishman in 32,000 could be a Fellow, one Frenchman in 427,000 and one Prussian or one Italian in 300,000 could be academicians. No country equalled Prussia in bestowing encouragements on science, but others fell only slightly behind. The French awarded titles of nobility to distinguished scientists, and a French report of English parliamentary proceedings referred to the intellectual distinction of a particular speaker; an English report, had it stressed anything, would have emphasized his wealth. France gave great financial awards to science, but England allowed such independence of opinion to go unrewarded.

In considering the general state of English learned societies, Babbage found cooperation and the division of labor as practicable in science as in industry. The want of competition stultified. Many different scientists, appreciating this deficiency in the Royal Society, had seceded, despite the bitter opposition of the parent society, whose attention to their specialty was insufficient to their wants and needs. In this way the Linnaean, Geological, and Astronomical societies came into being. In the case of the last, so successful was the persecution by the Royal Society that within six years it had become widely known and respected throughout Europe. By contrast, the Zoological and Medico-Botanical societies were founded without Royal Society opposition, and the latter totally failed.

Babbage listed thirteen learned societies, their fees, and their letters. The fees ranged from £ 21 for the Medico-Botanical Society to £ 50 8*s.* for the Antiquarian Society. Should a person desire he could become a comet with a tail of over forty letters, at the average cost of £ 10 9*s.* 9*d.*, and a farthing per letter. Among the societies Babbage picked out half a dozen for special comment. The Geological Society was doing pretty well, but its papers needed more finish; the Astronomical Society was a great success from any angle—excellent papers, open meetings, and rotating presidents; the Asiatic Society had done good work in translating rare works; the Horticultural Society had had a good record but now was ridden to death by its large debt. On the other hand, the Zoological Society was a source of great amusement. The Medico-Botanical Society had gone after social

lights, and its quackery rendered *expulsion* its highest honor—if it would only commit suicide it would exemplify the sublimest virtue.

It was against the Royal Society that Babbage brought up his heaviest guns. Properly he peppered the quacks with satire; but the Royal Society had played traitor to learning, and sorrow as well as anger inspired his comprehensive attack. Therefore, he described the mode of becoming a member, the administrative organization, the medals and lectureships, the causes of the present state, and a proposal for reform. Informing all these topics was an intense conviction that until the Royal Society was reformed science must remain at a comparatively low level.

The mode of election made it relatively easy for any man so desiring to become a Fellow. Three members put up his name and at the end of ten weeks—if he had done nothing whatsoever—he was elected. If he had written something his chances were much slimmer, for then some Fellows would assuredly inquire if his work showed sufficient merit to warrant his election. Blackballing, prejudiced or otherwise, was not final; neither was it the only means of keeping out the real scientist. The £ 50 fee excluded many such, though not, of course, members from the gentry.

The president and secretaries came in for sharp attack. President Davies Gilbert (1767–1839), an antiquary, was held to be, after some years as treasurer—to which office he seemed anxious to return—"by far the most fit person" available. It was true, said Babbage, that he was "a most amiable and kindhearted man," although in office, instead of raising the level of the Society's achievement or indeed of living up to his character, he had grasped despotic power and remained in the office to which he was elected as an *ad interim* figure and for which he had no competence whatever. The secretaries, Peter Mark Roget, M.D. (1779–1869), and Captain Edward Sabine (1788–1883), were incompetent. The presence of the second undoubtedly prompted the additional remarks concerning the propriety of a military man holding any office in the Society. It was not that such a person was necessarily inefficient but rather that habits of obedience and command rendered him unfit for such offices. The soldier must cover up his mistakes, the scientist must freely admit his. Babbage, however, hastened to add that no man should take criticism as personal, perhaps because Sabine was undoubtedly a superior member of the Society. The council was inadequate, and the union of several offices in one man was bad practice. The Society frequently showed a deplorable lack of integrity in learning and administration alike: it claimed other men's work as its own, and its written minutes by no means revealed the true proceedings. The funds of the Society were grossly misused.

Nowhere did these latter deficiencies appear more glaringly than in the awards of medals and lectureships. The members voted one another the medals, or else voted them to a proper recipient long after a specific achievement and in direct violation of the avowed purpose behind such medals, that is, to excite competition. The lectureships went year after year to the same men instead of being used to encourage some youngster. These criticisms undoubtedly had great validity. In particular, the Croonian Lecture, founded in 1738, deserved all the scorn that Babbage could direct at it, for from 1790 to 1829 the name of Sir Everard Home (1756–1832) appeared with monotonous repetition. In that interval only eight other persons, who between them gave twelve lectures, held the lectureship; on six occasions the lecturer and his subject were not recorded, and in one year (1828) no lecturer was appointed. All things considered, and perhaps not uninfluenced by Babbage's blast, no Croonian lecturer was appointed 1830–50. The Bakerian lectureship (founded 1775) did not show quite the same monotony, but for thirteen years, 1780–92, Tiberius Cavallo (1749–1809) was the lecturer. Afterward Samuel Vince (1749–1821) held it seven times in eleven years, and in following years the names of William Wollaston, Thomas Young, and especially Humphrey Davy appear frequently. Although no question attached to the merits of these three, the point made by Babbage had pertinence.

The cause of the low ebb of the Royal Society, then, was years of misrule, for which the responsibility must in part be laid at the door of the members who had failed to exercise their suffrages. It was of course true that they found it easy not to do so. A printed list of nominees, prepared by the president, was put in their hands, and for the most part no questions were asked. A coterie—a mutual admiration society—managed the Society. Any dissenter was silenced by the remark that either it was no concern of his, or, being his concern, he was the last who ought to raise a cry, or that he should wait until he cooled off (by which time he was told that it was too late), or that the rules were never adhered to anyway. Meanwhile the coterie surrounding the president and the beneficiaries of his patronage continued in charge.

To remedy those defects, which especially aroused his anger, Babbage printed a plan of reformation, a plan which indeed he and others, in-

cluding such eminent members as Herschel, Wollaston, Thomas Young (1773–1829), and James South (1785–1867), had formulated three years before. A committee had been appointed to consider means of limiting the number of Fellows and improving the Society's prestige, but its members unfortunately had not agreed on the way of realizing these aims, and this, combined with the natural disinclination for change and the power of the administration, had rendered the committee's recommendations ineffectual. As far back as 1674 the Society had considered the ejection of useless Fellows as one means of improving scientific standards; in the subsequent interval an occasional voice had urged without effect the same policy.

Now Wollaston thought to reduce the membership to 400 by not replacing deceased Fellows. Babbage thought this process not only too slow but also discouraging to younger scientists who could add luster to the Society that they would never be able to join. He himself suggested a test of two or more printed contributions to the *Transactions*, which would reduce the membership immediately to 72; if three or more became the test, which he preferred, the number would fall to 51; and even if all contributors were retained, the Society would have only 109 fellows. At the time more than 600 members got credit for nothing. Babbage also wished to renovate the council and institute more democratic election and freer discussion of policies.

The committee report, presented late in the 1827 session, contained the core of these suggestions. Satisfied that the Fellows had increased out of proportion to the growth of population or scientific knowledge, the committee made membership, which was to be limited to 400, exclusive of royalty and foreigners, an object of competition among deserving persons. Using the contributions to the *Transactions* as a clue, the committee decided that until the number of 400 had been reached only 4 new members were to be admitted annually. These would be chosen on the basis of merit, with full knowledge of the candidates' qualifications. No one would be excluded by arbitrary blackballing, and no disgrace or recrimination would accompany failure to be elected. A new committee on finance would guarantee a more judicious expenditure of funds in the face of falling revenue. There should be more publicity to awards, more thought to council choices, and more critical selection of papers for the *Transactions*. These recommendations were to go to a committee for framing and then be jealously and zealously scrutinized by the whole Society.

Despite the eminence of the original committee, the thought that had gone into their report, and the undoubted need for reform, nothing whatever emerged. On June 25, 1827, the council recommended the report to "the most serious and early consideration of the Council for the ensuing year." The president thereupon loaded the council according to his prejudices, and the report was rejected without any discussion of its merits. No wonder that Babbage traced the decline of science to the Royal Society, a view shared by South, a moving spirit in the creation and membership of the committee, and, far more moderately, by Augustus Bozzi Granville (1783–1872). The first published a very sharp pamphlet on the matter in 1830. The second published *Science without a Head* anonymously in the same year and *The Royal Society in the Nineteenth Century* in 1836. Granville, however, in some measure sought also to refute, or at least to soften, the strictures of the other two. His works, especially the second, were abundant in facts not readily available, sparing in argument, and economical in conclusions and recommendations; nonetheless, he believed the Royal Society "the only scientific corporation in Europe . . . *en arrière* of the century we live in," and suggested some fundamental changes. All three men, plus the committee's report and the undoubted prestige of its members, no doubt influenced the reforms of the 1830s. To Babbage, however, the damage was done, and he seems never to have forgiven the Society, even though at a meeting on May 27, 1830, "the President announced, in a good tempered speech, that the discontented members, Mr. Babbage and Mr. South, were for the present appeased; and that Capt. Sabine, having been summoned to join his company in Ireland, was obliged to resign the Secretaryship" (*Gentleman's Magazine*, C, pt. i, 544).

This of course did not halt suggestions from Babbage, either in the *Reflections* or in later works, for the advancement of science in England. First of all, he maintained the Fellows of the Royal Society must express their opinions. The managing coterie triumphed, he believed, because many qualified persons expressed their opinions reluctantly and timidly, and silence was cited as approval. This reluctance no doubt resulted in part from the scholar's modesty, partly from deference to a great name. The coterie triumphed also because presidents remained long in office. Biennial presidents had proved successful in the Astronomical and Geological societies; each man was anxious to accomplish something worth while during his tenure, and no man stamped his personality on the society.

Outside influences sometimes benefited, some-

times damaged, the Royal Society. In the case of the Colleges of Physicians and of Surgeons, the tendency of their members to join the Society was a disadvantage. Although the *Transactions* occasionally contained medical papers of "very moderate merit," medical men introduced their professional jealousies. Moreover, medicine had too many aspects, and its practitioners too many interests, to contribute much. The Royal Institution had a mixed effect. Designed originally to cultivate the more popular and elementary branches of science, it had through the efforts of Davy and the decline of the Royal Society gained greater prominence than anticipated. It had a good influence in the diffusion of knowledge and a bad influence, for the Society, in that its officers and transactions did not normally meet the standard that ought to govern the Royal Society. If the situation were not controlled, wrote Babbage, the Royal Institution might ultimately dominate the Royal Society; and certainly no man should hold office in both.

Of the *Philosophical Transactions* Babbage complained that they contained no history of the Society and its work, but merely a meteorological register, a notice of medal awards, and the papers selected by the council. There was not even a list of the officers and council; (but then to include this last would rob the porter of the half crowns he received for regularly distributing a separately printed list). Among other worthy items omitted were the names of the new and the deceased members, the conditions of granting medals, and the statutes of the Society. Actually, furthermore, to print 800 copies was unnecessary since many members had no real interest in the contents. On the positive side Babbage noted the regular and accurate publication of the *Transactions*, a characteristic to be imitated by all societies, especially by the French Institute, which was woefully remiss.

Finally, in the matter of encouraging science, Babbage made a few lesser recommendations. He stressed the need for an order of merit based on quality; knighthoods he feared would go to "mere jobbers" in science. Elevation to the peerage might have value. The union of scientific societies was desirable in many ways, not least as an economy measure. One large building would house their meetings, which could be scheduled without conflicts, and one library, which would prove a great advantage.

In a chapter not quite so germane to his central theme, Babbage concerned himself with "observations," in which he emphasized the value of minute precision, described the art of observing, warned against frauds, and passed some shrewd judgments. The last advances toward precision, he pointed out, required greater labor, but the first steps toward discovery added most to knowledge. Some men held that no experiments had value except the measurements be most minute; thus they diverted attention from points of greater importance. Genius was marked not by observations perceptible only to the most acute, but rather by achievements obvious to the common observer. In observing, one might safely trust the principles of common sense. He should find the limits within which an instrument could "measure the same object under the same circumstances." An elaborate instrument was worthless if it could not be used dependably; and its findings should be checked constantly. This was essential because observers sometimes put out fraudulent conclusions: the deliberate hoax—deception without wit—a vicious offense in that the products of nature were so various that a hoax might be convincing; forgery; clipping off bits from some observations, which differed most in excess from the mean, and sticking them on others; and finally the selection of observations which most agreed and the use of different formulas as if they were the same.

In conclusion, Babbage eulogized Wollaston and Davy, stressing especially the modesty of the first and the impulsiveness of the second. He also printed three appendices. The first described a scientific meeting at Berlin in 1828, reprinted the eloquent address of Alexander von Humboldt, and indicated the character of the scientists present; the second showed how personal favor often determined election to the Royal Society; the third listed the Fellows who had contributed to the *Transactions* or had been on the council.

In his incisive essay on machinery and manufactures, "perhaps the first adequate exposition of the economic bearings of the machine industry," Babbage gave only one chapter to science; the remainder dealt with the history of English manufactures, taxes, and combinations of masters and workmen. He could not forbear, however, pressing his scientific creed, especially as related to the situation in England and the dependence of applied on pure science. The connection of the latter should be intimate, he reiterated, and the discovery of theoretical truths should not only be protected by patents but, because of the expense, subsidized. In countries where science was a profession it was properly rewarded. Not so in England! The only high place to which a scientist might aspire—the presidency of the Royal Society—was held by the Duke of Sussex (1773–1843), who took office despite his narrow majority of eight over John Her-

schel. This clearly illustrated the evil days on which English science had fallen.

Happily, the British Association promised after only two meetings to remedy the deficiencies of the Royal Society. The benefits to science of such an association, properly run, were varied and significant. Chief among them was the intercourse between pure and applied scientists. In consequence, the sons of wealthy manufacturers might prove a hopeful source of future scientists; the economy of some "pure" discoveries to "applied" production might be more fully appreciated, especially the potential value of chemistry and physics; and the future prospects of neglected regions of the world might be emphasized.

Early in the Association's career Babbage contributed to its meetings. He recommended a collection of tables of all those facts which could be expressed by numbers in the various sciences and arts, and which he denominated "the Constants of Nature and Art" (*Report of the First and Second Meetings,* 2nd ed., 1835, 613). In some remarks on the vital statistics of an Irish parish, he declared that "to discover those principles which will enable the greatest number of people by their combined exertions to exist in a state of physical comfort and of moral and intellectual happiness, is the legitimate object of statistical science;" the data would ameliorate "the moral and physical condition of the people." He also reported favorably on cooperative shops (*Report of the Fifth Meeting,* 1836, 118, 125).

The examination of the exposition of 1851, nearly twenty years later, prompted Babbage to narrate the origins of the Association. Although major attention in this book went to political economy, science received considerable space. Because learned societies had long proved useful in resolving doubts and clarifying discoveries, the increasing technical complexity of science was begetting more specialized societies. One such, organized by Professor Oken (1779–1851), of Munich, was an annual assemblage of German naturalists meeting in different cities. Gradually this society had admitted representatives from other sciences, as well as foreigners. The generous welcome and the imitators of it testified to its success. At first, for instance, Austria was an intellectual desert, her rulers even refusing passports to her philosophers; that now was remedied, and Vienna was soon to entertain a meeting. Moreover, when Englishmen appreciated the success of the whole project, they sought to form a similar institution. At first grave difficulties arose because of the unfavorable position of science in England. Since the government recognized no obligation to science, it was indifferent to scientific progress and incapable of distinguishing the charlatan from the savant. Once founded, however, the British Association conspicuously reflected Oken's ideal in many respects.

Unfortunately the Association, now twenty years old, had not altogether realized its opportunity. Few qualified people attended the sessions, but Babbage thought that if it would meet in different cities and then convene in London, and if new sections and exhibitions were encouraged, its prospects would brighten. Under the inspiration of Adolph Quetelet (1796–1874), who once came to address the Association and found no provision for his "valuable budget" of documents, a statistical section had quickly gained recognition, and soon after the Statistical Society had been born. Properly supported, the Association would have greatly improved the Exhibition of 1851. Such societies needed encouragement, for many were created by popular demand, but they did not flourish in England. France had gone much further. Her Conservatoire des Arts and Métiers (1795), comparable to Gresham College, was very successful; and many other countries had followed suit. In England, rewards often went to persons broad in interests rather than original in contributions, and to those with an aptitude for figures. The pecuniary returns were poor, and in eleven years, in the midst of a veritable shower of party creations, only one baronetcy and six knighthoods had rewarded scientists. Babbage felt that many government posts should go to scientists, and pure science should be steadily honored. "It is of the very nature of knowledge that the recondite and apparently useless acquisition of today, becomes part of the popular food of a succeeding generation."

How far and how unfairly Babbage clung to his earlier prejudices appears in his references to the Royal Society. He harshly condemned its intrigues, and, despite the steady improvements of the preceding years, he declared it to be so hopelessly mismanaged that all efforts at reform had failed. Thereupon he repeated his criticisms of twenty years before. In France, only men of the highest intellectual attainment were the electors of the Institute, but in the Royal Society any one of the 800 Fellows, the greater part of whom knew no science, equalled any other in voting power. In contrast to the Paris Academy the secretaryships of the Royal Society went to third-raters and its presidency to men of exalted rank, whose other interests took first place. The Society also awarded its medals with great irregularity; prejudice, deliberate malice, and disparagement almost invariably took pre-

cedence over merit. Since pure science was inadequately recognized, its university chairs often went to men appointed not as scientists but as divines. Although much of this attack was no doubt literally true, Babbage made no allowance for a changing spirit in the Royal Society and the universities.

His autobiography, *Passages from the Life of a Philosopher* (1864), related his troubles with the calculating machine, his success abroad, his failure at home (to secure several learned posts for which he thought himself qualified), and his abomination of street music. To the eradication of this last he devoted as much energy as to the reform of the Royal Society and the elevation of science. He calculated the damage to learning, health, and music itself; he listed the instruments of torture—organs, bands, fiddles, harps, hurdy-gurdies, whistles, trumpets, and, not least, the human voice whether in advertising, canting, or singing; he found taverns, children, servants, country visitors, and "ladies of elastic virtue" the chief encouragers. Because of his efforts, however, noises redoubled outside his window, mobs hooted at him, dead cats were heaved into his areaway, his windows were broken, and he himself was struck. Occasionally he reverted to his earlier complaints about science, as when he characterized presidents of scientific societies as the "demimonde" of science, and when he derided the "erudite Professor Ponderdunder," a member of all existing academies, author of the remarkable metaphysical treatise, "On the Entity of Space," and promoter of "small science and low art."

He concluded by listing the personal "peculiarities" which enabled him to accomplish "what even the most instructed in their own sciences deemed impossible." During his waking hours he invariably followed some train of inquiry, trivial or profound; to avoid insomnia he pursued a trivial subject until he went to sleep; to accomplish something important he worked up the minor accessories during the day and between 2:00 and 6:00 A.M. tackled the essential problem. Early perceiving the immense power of science, he became convinced "that the highest object a reasonable being could pursue was to endeavour to discover those laws of mind by which man's intellect passes from the known to the discovery of the unknown."

When Babbage died the Royal Society printed no obituary. Perhaps it no longer regarded him a member, although in 1864 he had called himself such and in 1859 he had contributed "Observations on the Discovery in various Localities of the Remains of Human Art mixed with the Bones of Extinct Races of Animals" (*Proceedings*, **X**, 59–72). On the other hand, the president of the Statistical Society hailed Babbage as more than any other the founder of the Society, for it began at his house. Babbage, he went on, "took broad views of science" and explored many branches of knowledge; in 1839 he had read an informative paper on the statistics of the clearinghouse, and his study of machinery and manufactures was "a masterly analysis." Interestingly enough, the president referred in no way to the *Reflections* or the *Exposition of 1851* (*Journal of the Statistical Society*, **XXXIV**, 411–17).

Babbage also figured variously in less specialized periodicals. Some statements in the *Reflections* (pp. 62–65) led to an acrimonious controversy in the *Philosophical Magazine* (1830). The president and secretary of the Royal Society denied the charges concerning alterations of the minutes. Babbage replied; the secretary answered; and Babbage rejoined with the last word. Captain Edward Sabine also defended himself against the criticism in the *Reflections* (pp. 76–100), and *Socius* accused Babbage of pettiness, especially since he had contributed to the *Transactions* and held office in the Society. At the same time *Socius* recognized the need for the reforms suggested by Babbage (ser. ii, **VII**, 446–48; **VIII**, 44–50, 72–74, 153–59). Two years later, on the appearance of the essay on machinery and manufactures, the *Philosophical Magazine* (ser. iii, **I**, 208–13) put him in a much better light. Although specifying that the book was outside the sphere of a scientific journal, the reviewer insisted upon the need for becoming acquainted with so remarkable a work. The scientific reflections were "equally fitted for the perusal of the philosopher and the general reader." Babbage had clothed "the stores of his highly endowed mind with the richest drapery of language"—in description, perspicuous, in argument, concise.

The reaction of lay periodicals to Babbage possesses greater interest, and whatever they discussed, the opinions varied. *Blackwoods* (**XXXII**, 1832, 694) was "sick of the very name of this coxcomb Babbage. Such a cold dry, prig it is! So intensely ignorant, too . . . Babbage rhymes to cabbage;" the man writes "as pompously as the Pandects." The *Quarterly* (**XLIII**, 1830, 305–42) alone reviewed the *Reflections*, strongly complimenting Babbage's "varied and profound acquirements." As was customary, the reviewer actually examined the subject as a whole, and in so doing was "unceremoniously exposed" by Granville for "his *diatribe* on the scientific men of his own

country." The review especially underscored the contrast between England and every thriving country on the Continent, and insisted upon the need for more radical changes than those suggested by Babbage.

In sharp contrast *Fraser's* (**VIII**, 1833, 167–75) found the essay on machinery and manufactures deficient in every required condition of such a work. What was wanted was "not a treatise for a lady's boudoir . . . or a confused miscellany . . . but a treatise of solid and substantial merit," from a man keenly aware of existing needs. The deficiency of the work was the more obvious in that Babbage "stood second in British science at the time of its appearance," and had taken such a dim view of the prospects of science in Great Britain. Actually the large sale of this rubbish proved his contentions concerning the decline of science in England. Nevertheless, in considering the chapter on science, the review not only admitted the validity of Babbage's criticisms but actually, as had the *Quarterly* earlier, went farther. It did, however, belittle his opposition to Sussex, on the ground that no one paid any attention to the Royal Society anyway, that the Duke might rise above the trivial politics of the Society, and that the Society needed much more fundamental reform.

The *Edinburgh* fell between the extremes of applause and denunciation; on the whole it paid Babbage the high compliment of solid comment and lengthy attention. It discussed the history of the calculating machine (**LIX**, 1834, 263–327); and its disregard of Babbage's strictures on the Royal Society did not, as already noticed, arise from dissent. Not uncharacteristically, in reviewing his less controversial books, it adopted a down-the-nose attitude, but here as elsewhere "this won't do" symbolized an insistence on first-rate work. The reviewer of *A Comparative View of the Various Institutions for the Assurance of Lives* (1827) advised Babbage to confine his "comprehensive mind" to the "researches of abstract science." Here he had made "too bold a descent into the details of ordinary business," and he could not be congratulated on the success of his undertaking. The errors in his reasoning showed clearly that he was not at home with his materials (**XLV**, 1826–7, 482–513). In the essay on machinery and manufactures, a reviewer found "within a small compass a great deal of novel and interesting information, presented in a striking manner;" he also found it sometimes superficial, unsatisfactory, and incomplete (**LVI**, 1832–3, 313–32).

The conditions of science which aroused Babbage had already had a long history (Henry G. Lyons. *The Royal Society 1660–1940*, Cambridge, 1944, chap. vii; *The Record of the Royal Society*, 4th ed., London, 1940, 54–74). For decades the Royal Society had faced ridicule and secession. The increase in the number of Fellows during the eighteenth century, the relative diminution of the number of scientific members, and the Society's failure to promote science actively were widely deplored, as were the self-perpetuating council and the secrecy attending finances. Furthermore, the long presidency of Sir Joseph Banks (1778–1820), despite his positive beneficial achievements, had stereotyped the outlook; and at his death there was widespread feeling that science needed more emphasis, a conviction to which Banks himself had subscribed.

Although Banks was followed first by Wollaston (June to November 1820) and then by Davy (1820–27), and the new council contained 12 instead of 7 or 8 scientists among its 21 members, no revolution occurred. Davies Gilbert and the Duke of Sussex presided from 1827 to 1838. Davy himself soon emphasized social rather than scientific distinction; in addition he proved a tactless, arbitrary, and impulsive administrator. Moreover, his chagrin over the failure of a recommendation to the Admiralty restricted his activity after 1825. This permitted the dominance of Gilbert, a persistent opponent of reform throughout his entire connection. Several years elapsed before genuine scientists regularly controlled the council, for some new members after 1820 were scarcely more than "courtesy" scientists.

If the scientists did not take over the Society in the 1820s, they were sufficiently influential to open the door to such a development a generation later. Upon Davy's resignation in 1827 Gilbert's effort to elect Sir Robert Peel, then Home Secretary, aroused so much hostility that the matter dropped, but Gilbert himself took the chair and appointed a council—including the reactionary Lord Colchester (1759–1827) in case legal assistance was needed—which suppressed the reform report at its first meeting. In 1830 Gilbert further showed his hand by picking the Duke of Sussex as his successor. This, with his earlier activity and his appointment of the Bridgewater lecturers, aroused criticism, but not enough to unseat him or destroy his influence. Nevertheless, Society affairs received such an airing that better prospects were at once apparent. Sussex showed some sympathy with reform, although as time went on he left affairs more and more in the hands of reactionaries until 1838. Thereafter improvement occurred rapidly. Whereas in 1830 nobility comprised over 10 percent of

the membership, in 1860 the proportion had fallen to 4.5 percent and was steadily diminishing.

Equally important was the growing emphasis upon scientific, productive Fellows. The breakdown of the membership in 1830 into its component parts reveals how much such emphasis was needed if the Society was to improve natural knowledge. The 10 episcopal members had contributed 9 papers to the *Transactions,* all by one of their number; 63 noble members had contributed nothing to the *Transactions*; 66 military and naval officers had contributed 35 papers, but 25 came from 2 military members; 74 lesser clergy had contributed 8 papers, and 63 legal members 28 papers, 16 by one man; 100 physicians and surgeons had contributed 203 papers, 109 by Sir Everard Home. The 285 other members, who included "pure" scientists and men about town, had contributed 205 papers. Out of 488 papers in the *Transactions,* 408 had come from "pure" and applied scientists, and 50 more had come from 4 other men.

How far this situation prompted a change remains obscure, but henceforth, although any candidate could be elected, six instead of three supporters of his certificate were required. Moreover, lists of the council members and the officers were made available before the anniversary meeting, and the treasurer's accounts and the council's report were published. In no sense revolutionary, these changes at least suggest some triumph for the critics. Other reforms followed; and in 1840 the election of W. R. Grove, though he was a nonscientist, added a powerful recruit to the science faction on the council. Scientists still formed scarcely more than a third of the Society, but after 1842 the number of new Fellows elected each year fell off significantly. Scientists completely dominated the council in 1845–46, and in 1847 came some drastic changes along lines sought twenty years before Babbage. By 1860, the Society had become scientific.

Interestingly enough, the sort of criticism heaped on the Royal Society found expression in other spheres. Thomas Wakley (1795–1862) saw favoritism and nepotism rampant within the medical profession and founded the *Lancet* in 1823 in protest against abuses in the College of Surgeons and elsewhere. In 1846, he as a Member of Parliament introduced a bill for reforming medical practice. It failed, but its essence went into a law in 1858. At the same time the universities, especially Cambridge, were waking from a long sleep and facing the new demands.

To cast up the accounts of Charles Babbage is not difficult. Notwithstanding the fundamental validity of his contentions, the solid comment of Granville and the testimony of history refuted his more extreme affirmations. He was, for his own purpose, too petulant and incidental. His disappointments led him into misrepresentation if not downright error. Science *was* a profession and so rewarded; the Duke of Sussex, whether he should have been elected or not, turned out better than some "scientific" presidents; the derelictions of the universities and the government had always existed; British science, never on a par with Continental in discovery and interpretation, had fallen no farther behind; the stress upon the number of contributions to the *Transactions* was invidious.

In tracing "the gradual decline of mathematical and with it of the highest departments of physical science," Babbage too closely identified the Royal Society with science. Although for one hundred fifty years they had seemed one, they were, after all, not the same. The newer societies belied his pessimism, for by his own admission several exhibited the liveliest interest in science and appeared the likeliest agents for its advancement. Moreover, the contemporary intellectual depression and administrative oligarchy of the Royal Society only marked a stage through which every learned society goes some time or another. In the century since his fulminations, many societies have irritated their more scholarly members. The piddling raffle of politics, the perennial committeeman, favoritism and snobbery, and the awarding, on the basis of age or distinctions other than intellectual merit, of honors to which the scholar alone may aspire flourish as they did in Babbage's day.

More generally, Babbage failed to appreciate that each country's ideals are shaped by its history and rooted in its environment; in their origin and growth they are as social as institutions. Science in England was made and supported by Englishmen in their own way. Admittedly they stressed application, wherein they surpassed the Continent as far as the Continent outstripped them in discovery and philosophical interpretation. That stress had values beyond utility. No one will deny the benefits of qualitative selectivity; at the same time no one can disregard the consequence of divorcing the laboratory from the larger social scene. The English scientist knew fewer formulas; perhaps he knew more humanity. By keeping his feet on the ground he did not reach the stars, but neither did he pursue hypotheses irresponsibly. Any scientist appreciates his moral responsibility most directly when he considers his researches in terms of their social application. This he must do when he submits his discoveries to the judgment of an informed laity

as well as to his fellow-technicians. The investigator who has not scrutinized his hypotheses and tenets through a glass brightly, who has not related one scientific assumption to others, who has not checked them against each other and against established truths outside science, may become a thriving gadgeteer, but he will certainly make a sorry citizen and a sorry scientist as well.

Whether Charles Babbage comprehended matters of this sort is not clear, but, for all his arrogance, he was a humanitarian, and no mere doctrinaire. What he sought so ardently was not less application but more original discovery. No one familiar with the history of any branch of knowledge can doubt the essential soundness of his position; nor, so far as we are concerned here, can one doubt that he successfully needled his learned contemporaries into general agreement with him.

ITINERARY

SECOND (1948) ANNUAL INTERNATIONAL PHOTOGRAPHY-IN-SCIENCE SALON

CRANBROOK INSTITUTE Bloomfield Hills, Michigan	October 1–30
BUHL PLANETARIUM AND INSTITUTE OF POPULAR SCIENCE Pittsburgh, Pennsylvania	November 6–30
FRANKLIN INSTITUTE Philadelphia, Pennsylvania	December 6–31
SCIENCE ILLUSTRATED New York City	January 6–20
GENERAL FOODS CORPORATION Hoboken, New Jersey	February 3–24
BROWN UNIVERSITY Providence, Rhode Island	March 7–26
GAMMA SIGMA EPSILON University of Florida Gainesville	April 15–May 1
UNIVERSITY OF CALIFORNIA Berkeley	May 15–30
AMERICAN OSTEOPATHIC CONVENTION St. Louis, Missouri	July 11–17
PENNSYLVANIA STATE MUSEUM Harrisburg, Pennsylvania	September 5–26
ROYAL PHOTOGRAPHIC SOCIETY London, England	December 1–31

PINEAPPLES IN ANCIENT AMERICA*

J. L. COLLINS

Dr. Collins (Ph.D., University of California, 1923) has been geneticist and head of the Department of Genetics at the Pineapple Research Institute of Hawaii since 1930. In 1938–39 he conducted an expedition into South America to look for wild and semi-wild species of pineapples, covering areas in Brazil, Argentina, Paraguay, and Bolivia.

IN THE early morning of Sunday, November 3, 1493, the fleet of vessels under the command of Christopher Columbus on his second voyage to the New World, made a landfall in the lesser Antilles of the West Indies. A landing was made on the first island they approached, to which Columbus gave the name "Marie-Galante." They soon returned to their ship and sailed for a larger, mountainous island visible in the distance, on which they landed Monday, November 4, 1493. Columbus gave to this island the name "Guadeloupe." According to the chronicle of Peter Martyr, here, at an Indian village, they found pineapple plants and fruits, "the flavor and fragrance of which astonished and delighted them." This is the first recorded contact of European people with the pineapple.

Although the pineapple represented a new and exotic fruit to these Europeans who sailed with Columbus, it appears to have been a common and an important element in the diet of the inhabitants of tropical America in pre-Columbian times. How widely the fruit was distributed and used by the Indians is to some degree indicated by the records left by those adventurous souls who penetrated many tropical regions during that romantic period of exploration and adventure following the discovery of the New World.

The pineapple shares the distinction accorded to all the major food plants of the civilized world of having been selected, developed, and domesticated by peoples of prehistoric times and passed on to us through one or more earlier civilizations. The pineapple, like a number of other contemporary agricultural crops such as corn, potatoes, tobacco, beans, and peanuts, originated in the Americas and was unknown to the people of the Old World before the discovery of America.

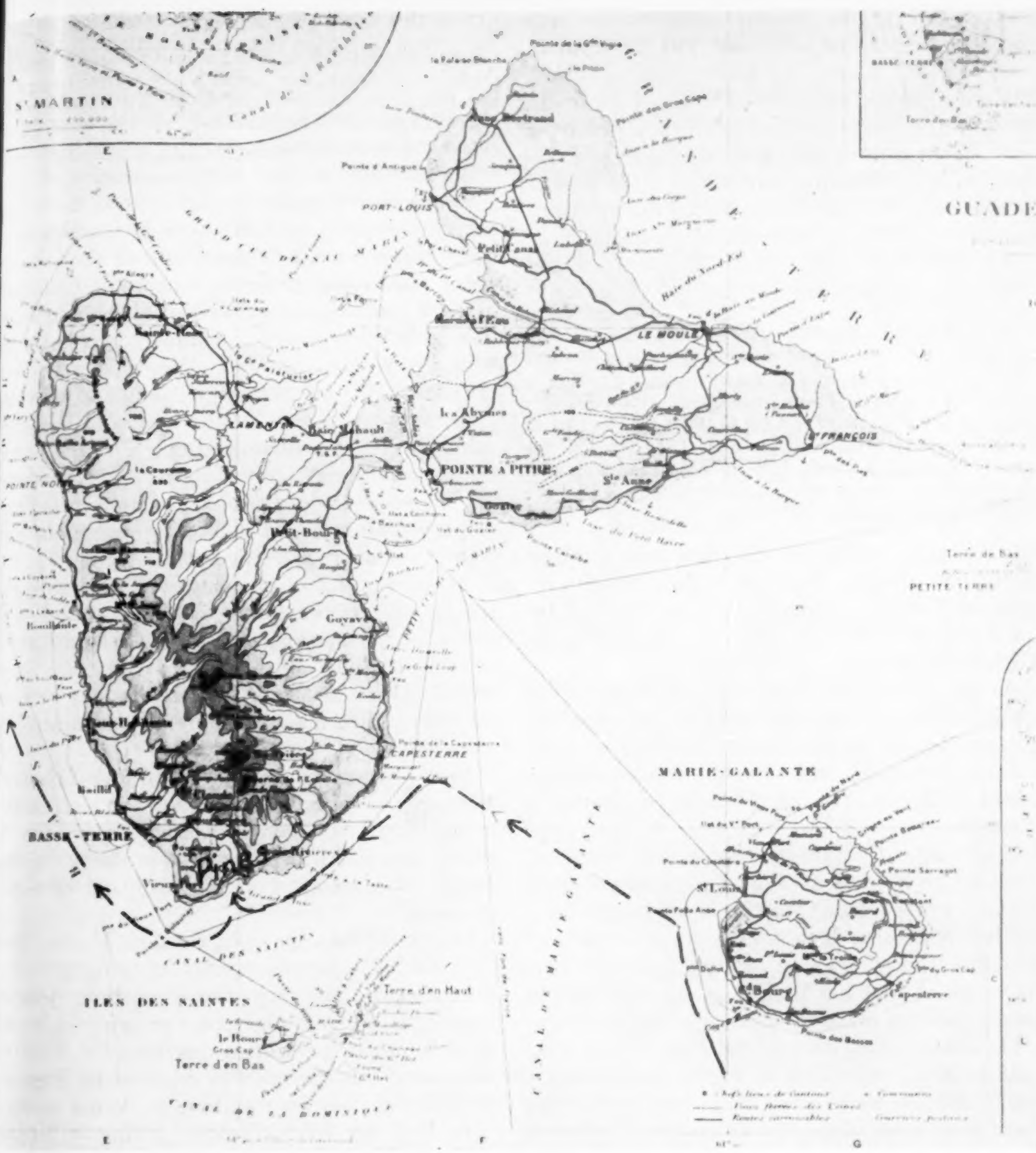
The Indians of tropical America had developed and named a number of different varieties of pineapples, selected by them or their ancestors because of their size of fruits, good quality, and absence of seeds. Wild pineapples that are probably the foundation stocks from which these domestic varieties were derived are still to be found in tropical America, but they are generally small-fruited, inferior in eating quality, and extremely seedy. None of these can be singled out now as the form or forms which gave rise to the domestic pineapples of today or even of those varieties in the possession of the Indians at the time of the discovery of America.

The pineapple appears to have been used very little by the native American tribes in their religious ceremonies, for which reason it has not been found as a motif for pottery designs, temple ornaments, and other decorations, as were corn and potatoes. There is some evidence, however, that it may have figured in some of the religious rites of the Indians of Mexico, for Acosta in his *History of the Indies* gives a detailed description of an Indian god which he described as holding in his left hand a white target with five pineapples made out of white feathers and set in the form of a cross. Since this god was used by the Indians previous to the introduction of Christianity, the image was probably made long before the coming of Europeans. This would then indicate that the Indians of Mexico were acquainted with pineapples in pre-Columbian times.

Thompson believed that the Maya Indians of Central America were not acquainted with the pineapple before the discovery of America by Europeans. He discusses this possibility as follows:

> The pineapple (*Ananas sativus*) possibly did not reach the Mayas until shortly after the conquest. The Prospero Indians who were entirely cut off from Spanish influence were found to be cultivating the pineapple when first visited by Europeans in 1646 (Cogolludo, Book XII, Chap. 7). This, of course, is not direct evidence that the pineapple was known to these tribes before the arrival of the Spaniards in the new world, as many of the articles introduced by them passed from tribe to tribe and were well established in remote areas long before Europeans had penetrated so far. Pineapples were certainly cultivated in the Cueva region prior to the conquest (Oviedo, Book XXIX, Chap. 29) and on the Mosquito Coast (M. W.) and the Usamacintla basin (Tozzer, 1912). . . . In view of the close relations between the Chiriqui area and the Mayas as demonstrated by the importation into Chichen Itza of gold objects from this region, it is not unlikely that food products of the two areas were interchanged.

* Published with the approval of the director as Miscellaneous Paper No. 46 of the Pineapple Research Institute, University of Hawaii.



The island of Guadeloupe in the West Indies, where pineapples were first seen by people from the Old World when Columbus landed here on his second voyage to the New World in 1493.

The Relacion Breve relates that Father Ponce was received during his journey to Yucatan in 1588 at many of the Maya villages with gifts of pineapples.

Thompson also points out that there is no word in the present Maya language for the pineapple and that the Spanish *piña* is used. This, he believes, does not necessarily mean that the pineapple was unknown to the Maya before the Spanish Conquest, since the Maya Indians have accepted Spanish words for other things, the earlier Maya terms being known only to a few of the older Indians at the present time. In a letter to the author in 1946, Dr. Thompson stated that he would now consider that the Maya of the peninsula of Yucatan did not have the pineapple but that the Maya of other Central American regions did have it in pre-Columbian times.

Stephens found what he believed to represent a pineapple made of stucco mounted on a circular base, used as an ornament in front of a small shrine

or altar among the ancient ruins on the seacoast of Yucatan at Tuloom. His illustration, when viewed under low-power magnification, shows a scalelike surface which could represent the eyes (or individual fruitlets) of a pineapple fruit. Stephens presents arguments in favor of this town being inhabited by the Indians at the time of the discovery of America, concluding that the ruins examined in 1840–41 were not of great antiquity.

The following is quoted from Stephens' account of his visit to these ruins:

> Near the foot of the steps overgrown by the scrubby wild palm, which covers the whole cliff, is a small altar with ornaments in stucco one of which seems intended to represent a pineapple. These wanted entirely the massive character of the buildings and are so slight that they could almost be pushed over with the foot. They stand in the open air exposed to strong easterly winds and almost to the spray of the sea. It was impossible to believe that the altar had been abandoned 300 years.

The 300 years would take the date back to about 1540, approximately the time of the Spanish conquest of Yucatan. Stephens believed that the Indians had continued to use these buildings long after the conquest.

A. M. Tozzer, who has made comprehensive studies of the culture of the pre-Columbian inhabitants of Central America, stated in a personal communication that he was sure this ornament mentioned by Stephens could not have represented a pineapple.

Cook states that the pineapple was known in Peru before the arrival of the Spaniards and gives the Inca name (*Achupalla*) for it; on this he bases his belief that the Inca Indians were acquainted with this fruit. This is the only indication we have so far found that the Indians of the west side of South America knew the pineapple before 1492.

De Oviedo, who lived in the New World from 1513 to 1547, voiced his belief that the pineapple was an old and well-known fruit when he observed that "In all these islands [West Indies] it is a fruit which I hold old and very common, because they are found in all these Islands and on Tierra Firme" [mainland of Central and South America]. He described three distinct varieties grown by the Indians of Haiti and produced the first illustration of a pineapple. This is a pen drawing used to supplement his description of a pineapple, which he admitted lacked exactness.

Columbus found pineapples being cultivated in fields by the Indians in 1502 at a place he called Puerto Bello on the Atlantic coast of what is now the country of Panama. His son Ferdinand reported finding pineapples being cultivated at Veraqua in this same general region in the year 1503:

> They make another wine of the fruit we said is found in the Island of Guadeloupe, which is like a great pineapple; it is planted in great fields and the plant is a sprout growing out at the top of the fruit itself, like that which grows out of a cabbage or lettuce. One plant lasts three or four years and bears.

Again, during his last voyage in 1503, Columbus found pineapples growing at Belen, which is a short distance north of the mouth of the Panama Canal. According to Irving's account, Columbus in 1503 landed on the island of Guanaja a short distance off the coast of Honduras, where he traded with a large canoeload of Indians who were quite different in appearance and clothing and who had apparently just arrived from Yucatan. They had come intent on trading with the Indians of the island and brought cotton cloth, copper utensils, pottery vessels, cocoa, beer made from maize, and wooden swords edged with sharp pieces of flint of a type found in Mexico at a later date.

In 1503, while Columbus was exploring the coastal area of Panama, "He again heard of a nation in the interior, advanced in arts and arms, wearing clothing and being armed like the Spaniards." These incidents indicate trading between the interior and the coastal area where pineapples were found by Columbus.

In 1519, only twenty-six years after Columbus first saw the pineapples on the island of Guadeloupe, Pigafetta recorded pineapples growing in coastal areas of Brazil, which is probably the first record of pineapples on the mainland of South America.

Gerommo Benzono, who lived in Mexico from 1541 to 1555, records pineapples being grown in that country, and about this same time, Jean de Lery again records pineapples growing in Brazil. Whether this represents a new area for Brazil or whether it was the same as reported by Pigafetta some twenty-two years earlier, we do not know.

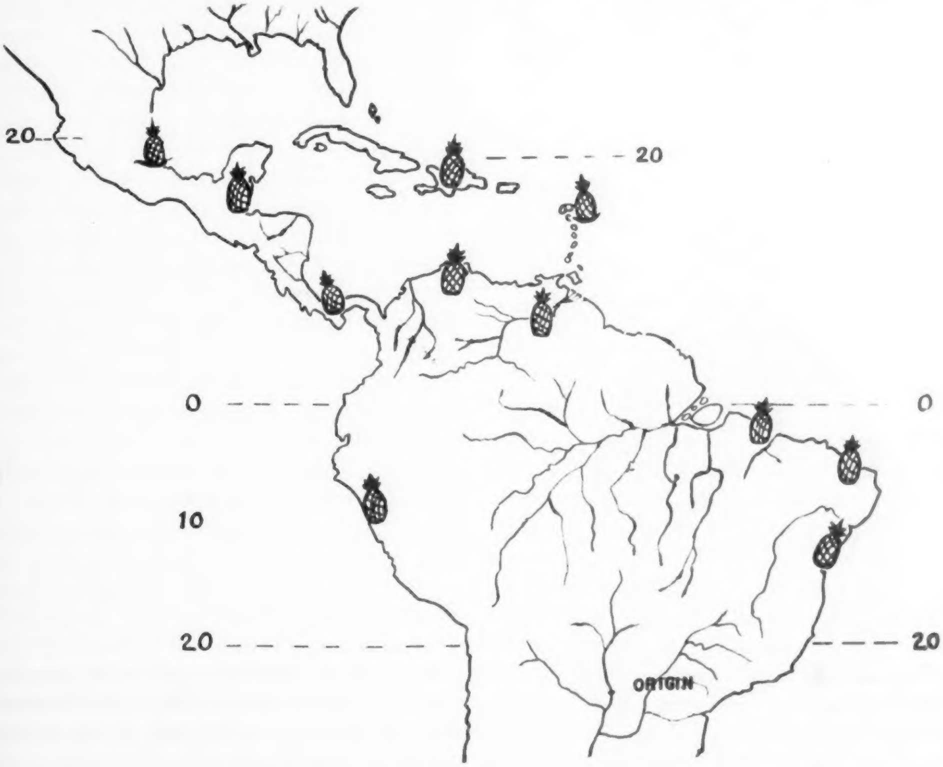
In 1565 Sir John Hawkins, sailing in his ship *Jesus of Lubeck*, stopped at a place along the coast of Venezuela known then as Sante Fe, in order to take on supplies of water and provisions. Here he received from the Carib Indians, who were described as naked savages armed with poisoned arrows, "hennes potatoes and pines." These latter were pineapples "of the bigness of two fistes." The inside of these pines was said to "eateth like an apple but is more delicious than any sweet apple suggared."

In 1595 Sir Walter Raleigh made his remarkable expedition some 400 miles up the Orinoco River in northern South America. He reports hav-

ing secured quantities of pineapples from the Indians in trade at various points while ascending the river. This observation was made one hundred and two years after the discovery of America, and one might well argue that the pineapples could have been introduced into this area in the intervening years and that it does not necessarily represent a pineapple area of pre-Columbian times. Neither do we know about the amount of communication between the Indians of the coastal area of Panama, where pineapples were known to exist in pre-Columbian times, and the tribes in the interior of the country. However, the fact that Sir Walter Raleigh found them in some abundance and that the Indians also made a kind of wine from them argues for a long-time presence in a country inhabited by primitive people having limited means or inclination for travel and transportation.

In 1637 Frans Post, a Dutch painter, came to Brazil as a government official while the northern part of Brazil was under the domination of the Dutch government. During his stay in Brazil, he painted a large number of landscape, seaport, and village scenes portraying the country and customs typical of Brazil at that time. Among these paintings, twelve (and possibly more) show isolated pineapple plants as a part of the native vegetation. From these paintings we may conclude that pineapples were a common feature of the north Brazilian coastal area in the early part of the seventeenth century.

Laufer, in discussing the migration of the pineapple, believed that the absence of the seeds in the cultivated species was induced by long-continued asexual reproduction and thus served to indicate a great age for the cultivated species. This belief that long-continued asexual reproduction induces or causes the loss of seed production, at one time quite current in regard to seedless fruits in general, has been shown to be erroneous. Seedlessness usually first appears in plants as a result of mutation in the chromosomes (a hereditary change) or as a consequence of hybridization, which is thereafter perpetuated by the asexual method of propagation. It is not difficult to call to mind examples in horticulture of plants long propagated asexually that still produce seeds. In the cultivated pineapple in Hawaii, new mutations (reverse mutations) have been found and perpetuated by asexual propagation which permit the development of seeds in the



This map, showing the distribution of pineapples in tropical America at the time of the discovery, is based upon records left by the early explorers.

formerly seedless variety. Thus, the commercial seedless variety has suddenly reverted while under cultivation to a seedy condition. The seedlessness of the pineapple cannot be considered as an indication of its age as a cultivated plant.

The early explorers of America were primarily interested in the search for gold, finding a sea route to the Indies, or carrying the gospel to the native peoples, whom they looked upon as heathens, and probably had little interest in transporting plants from one part of the new country to another.

Earliest known pineapple illustration—produced by Oviedo about 1520. It appeared in his *History of the Indies,* published in Seville in 1535. (Reproduced from the handwritten manuscript No. HM 117 by permission of the Huntington Library, San Marino, California.)

Therefore, the records they made of pineapples being present in different places may be accepted as evidence of their establishment there before the country was invaded by these semicivilized Europeans.

The medicinal and other qualities attributed to the pineapple by the early travelers and colonists indicate a long-time association with the fruit to provide for the development of these beliefs—much longer indeed than the short period of sketchy European contact with the pineapple. These beliefs regarding the medicinal qualities of the pineapple must have been developed by the Indians through their long association with the fruit and passed on to the newly arrived Europeans, who then made these qualities a matter of record.

The area or place of origin of the pineapple whence it was disseminated to other tropical American regions, is still a matter of some uncertainty, but opinion of botanists generally favors a region in South America near the middle part of the Parana River and the drainage of the Iguassu River, a region including southeastern Brazil, Paraguay, and Northern Argentina. This area also seemed to be indicated by the studies of the distribution of wild species of pineapple by Baker and Collins in 1938 and 1939.

In this region lived the Tupe-Guarani Indians in pre-Columbian times (some still do so), a hardy, intelligent, warlike people who migrated northward and westward until some branches of the tribes crossed the Amazon and reached the seacoast of northern South America. The Carib Indians who occupied northeastern Brazil continued the northward expansion and had extended into the islands of the Caribbean Sea before 1492. These tribes are believed to have carried the pineapple along with them and introduced it to other tribes in these new areas, and they in turn passed it on to their neighboring tribes. Thus, by a dual process of tribal migration and border trading between tribes, the pineapple was spread throughout tropical America.

We are somewhat puzzled as to the interpretation to be given three references indicating the possible presence of the pineapple in the Old World many centuries before the time of Columbus. These statements cannot be ignored in the present discussion of pre-Columbian pineapples and are accordingly included, together with the general opinion regarding them.

Layard and Rawlinson both describe some stone carvings on the walls of the ancient Assyrian city of Nineveh in which are shown different articles of food served at a banquet, including one that both

writers listed as representing a pineapple. Rawlinson stated that "The representation is so exact that I can scarcely doubt the pineapple being intended." Layard expressed some doubt about the Assyrians being acquainted with the pineapple but argued that "the leaves sprouting from the top proved that it was not the cone of a pine tree or fir."

The third reference to the presence of the pineapple in the ancient civilizations of the Old World is that of Wilkinson in *Manners & Customs of the Ancient Egyptians*. He states that "Among the numerous productions of India met with in Egypt which tend to prove an intercourse with that country may be mentioned the pineapple, models of which are found in the tombs of glazed pottery. One is in the possession of Sir Richard Westmacott." Wilkinson seems to believe that the pineapple was a product of India, but there is no evidence that it was grown in India or Asia during that period. Marco Polo, who visited India and Asia centuries later and who described with considerable accuracy many of the products of those countries, makes no mention of the pineapple.

The pineapple is so constituted for survival by its vegetative method of reproduction and the ability of these vegetative shoots to remain alive for long periods of drought or neglect that it is very improbable it could have disappeared completely from these countries had it existed there. Other food-supplying plants known to those regions have survived the passing of ancient civilizations. The fact that the pineapple was not handed down through successive generations and civilizations, along with such plants as wheat, dates, pomegranates, melons, etc., seems to be sufficient evidence that it had never existed there.

The pineapple belongs to the family of plants known as Bromeliaceae, which includes numerous species of terrestrial and epiphytic plants, all except one being native to America. This one species is indigenous to the west Coast of Africa.

Ames, in discussing the relationship of economic annual plants and the development of human cul-

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Hanc H. Lugdun. pag. 1840. Nana Brasilianorum Theueto : Item pag. 1841. Nana fructum, siue Yayama nominat.

De hac loquitur Maffeus Ind. lib. 2. In Brasilia ex omni genere fructuum palma tribuitur iis quos vulgus Ananazes appellat, planta est humilis, cuius è ramis veluti pinea nucamenta dependent, praemollia, hæc suo tempore in frusta desecta, gratissimul odore ac sapore non recenti duntaxat edulio sunt, verùm etiam in longum tempus adseruantur è Saccharo.

Drawing of the pineapple called *Yayama* by Oviedo. One of the three varieties described by him in his history of the Indies. (From Bauhin, J. *Historiae Plantarum Universalis*, 1651.)

tures, stated that the completed species indigenous to America exhibited all the characteristics indicative of great age that are shown by the economic plants forming the basis of ancient civilizations in the Old World. He concluded that "The sum of biological evidence leads to the conclusion that the cultivation of economic annuals of the New World must reach back as far into human history as the origins of agriculture in the Old World." The pineapple shares these characteristics of great antiquity along with the economic annuals of the same country.

A long period of prehistorical development for the cultivated pineapple is indicated by its wide distribution, the presence of several distinct cultivated varieties, its use as food, wine, and medicine at the time when America was discovered, and the absence of a recognizable wild progenitor.

SCIENCE ON THE MARCH

THE SCIENCE OF SANITATION

TRANSLATION of progress in science into forms that influence our personal living and economic life is an everyday occurrence. This transition, unobtrusive though it may seem, is often the result of an orderly progression through a network of technical organizations, trade associations, governmental agencies, and private industry, all working together to convert the findings of science into useful articles and methods.

The science of sanitation, which has reached a high level in the United States, has been furthered for over three decades by the National Association of Insecticide and Disinfectant Manufacturers, Incorporated.* This trade association is an organization of leading manufacturers of household and industrial insecticides, disinfectants, cleaning compounds, sanitary chemicals, and related products and equipment that are the tools of sanitation. Like other trade groups, it serves as a common meeting ground and spokesman for the industry. Binding it together are its established objectives—the promotion of technical and ethical standards for the industry, the education of the public concerning its products, and the sponsoring of scientific research.

The National Association of Insecticide and Disinfectant Manufacturers (we can call it NAIDM for short) was founded in 1914 by a small group of manufacturers who met to discuss problems of mutual interest—problems characteristic of a new and rapidly expanding industry—standardization and regulation, product development, and consumer education.

Thirty years ago, when NAIDM was entering the picture, quite a number of sanitary products were available to the public. By present-day standards many of them would be regarded as obsolete, now being considered either unduly harsh in action or else relatively ineffective. But scientific control methods were not so common, and chemistry had not yet produced the variety of organic chemicals we now employ as weapons against insects, rodents, and infectious germs. Today's modern chemical products for sanitation are on a sound standard of quality—the result of cooperative research financed by NAIDM or conducted by its committees and members.

One of the first problems of the growing industry was the need for classification of the various types of sanitary products into logical groups. This work, hampered by conflicting terms and definitions, was aided when the NAIDM sponsored a fellowship at Antioch College to define such terms as "antiseptic," "germicidal," "disinfect," etc. The results of this study appeared in the *American Journal of Public Health* in 1932.

Standardization of the types of products, with the ultimate aim of establishing a system of grades to govern buying and selling, has always been an important function of the Association. Some phases of standardization can be made on a chemical assay, whereas other phases require a biological evaluation. In the case of common fly sprays, for example, the ingredients can be purchased on chemical or physical tests, but in the finished product the ingredients may function synergistically so that performance can be rated only by trials on living insects. One of the best-known activities was the refinement and official adoption in 1932 of the Peet-Grady method for rating household insecticides, a procedure that has been widely used throughout the world for many years. To further utilize the Peet-Grady method, NAIDM made available to the entire industry the Official Test Insecticide, the "yardstick" on which is based U. S. Commercial Standard CS 72–38 for insecticides.

Similar Association activity in the field of disinfectants has led to many improvements in the widely used phenol coefficient method of rating these products. U. S. Commercial Standards for hypochlorite, pine oil, and phenolic disinfectants promoted by NAIDM have been in use for many years. Recent cooperative research undertaken by NAIDM and the U. S. Department of Agriculture on methods of testing the important group of quaternary ammonium disinfectants was published in 1947. Another group within the Association is investigating and promoting standards for special soaps, floor treatments, self-polishing waxes, and other sanitary specialties.

Fellowships at Ohio State University and at Wilmington College have been established to

* Executive offices of the Association are located at 110 East 42nd St., New York 17.

tackle such problems as the evaluation of roach sprays and powders, DDT residues, and aerosol bombs, under Association sponsorship. In its own members' laboratories, NAIDM committees have contributed greatly to the knowledge of mothproofing treatments and their evaluation; to the improvement of livestock sprays; and even toward the establishment of safe standards of slipperiness for floor wax. Rosters of these committees include the names of many of the country's leading scientists in chemistry and the biological sciences.

Because the Association encompasses a wide variety of products and because finished products represent a blending of numerous skills, its activities are concerned with many of the sciences. As one would expect, entomology, chemistry, and bacteriology play the leading roles, although the medical and physical sciences, as well as engineering skills, are often called upon. To cite the example of the fly spray again, it is necessary to use containers of a certain design because contact with lead solder or copper can destroy the insecticidal action of pyrethrins. Sprayers and similar devices for applying insecticides and disinfectants are important aids to sanitation, and their development is followed closely.

To accomplish exchange of technical and scientific information, NAIDM maintains close liaison with the U. S. Department of Agriculture, the U. S. Public Health Service, the National Bureau of Standards, and with other technical groups such as the American Society for Testing Materials, the American Association of Economic Entomologists, and the American Chemical Society.

The sanitary products industry, like many other economic groups, has gradually become a highly regulated business. Particularly is this true in the case of insecticides, fungicides, germicides, rodenticides, and weed killers. Within the past few years, most of the states have adopted new laws governing these products, and in 1947 the long-outmoded Federal Insecticide Act of 1910 was replaced by a much stronger and broader law. The Federal Food, Drug and Cosmetic Act and the various fair-trade laws covering advertising also enter the picture.

To keep pace with this increasing governmental activity, the Legislative Committee of the NAIDM has served an important function since the depression days of the NRA. Efforts of this group have not been to oppose regulation but rather to shape the laws to give adequate protection to the public without imposing stifling and costly barriers on the industry. That these efforts have been rewarded is evidenced by the fact that all Federal and state insecticide laws are now closely patterned after a model law sponsored by NAIDM in cooperation with other trade organizations and professional groups. To reduce the burden of keeping the scientists and executives of the industry posted on the many laws and regulations governing the manufacture and sale of its products, the Association made available in November 1947 a comprehensive *Compilation of Laws* with an annual revision service. This valuable work can be obtained by both members and nonmembers from the Association office.

As a trade association, its major function of establishing ethical business relations and promoting a spirit of cooperation has indeed been accomplished. Growth of the NAIDM, which in turn is a measure of outstanding service to a growing industry, is evidenced by the increase in membership shown below:

1915	15 firms (first year of organization)
1925	25 firms
1935	108 firms
1945	207 firms
1947	269 firms

Meetings are held twice a year, usually for a three-day period in December and in June. A résumé of each meeting, as well as many of the scientific papers and addresses, is presented in the trade magazine *Soap and Sanitary Chemicals*, which is the Association's official publication. Current items of a scientific nature, as well as general information, go forward to the members promptly in frequent bulletins.

At thirty-four years of age, the National Association of Insecticide and Disinfectant Manufacturers has yet to reach its prime. Its members look forward confidently to many more years of increasing service to industry, science, and the public in general.

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BOOK REVIEWS

Русский язЫк для уценЫх

Chemical Russian Self-Taught. James W. Perry. vii + 221 pp. $3.00. *J. of Chemical Education.* Easton, Pa.

AT THE present time, when the study of the Russian language in colleges and universities is being placed on an equal footing with that of French and German, especially for students majoring in science, the meagerness of good textbooks and good teachers is an acute problem. Any book that can alleviate this condition is to be greeted with enthusiasm. *Chemical Russian Self-Taught,* by Perry, goes a long way toward fulfilling the need of the student interested in studying scientific Russian.

The book contains seven chapters: Aptitude for Learning Languages; Suggestions for Study Methods; The Vocabulary Problem; Inorganic Chemical Nomenclature; Organic Chemical Nomenclature; Russian Grammar; and Glossary of Russian Technical Terms.

In his foreword the author encourages the chemist who is interested in learning Russian in order to be able to read and understand Russian chemical articles, and discusses in his first two chapters aptitude for learning languages in general and method for studying Russian in particular. Without question many of his suggestions will be of aid to the student. This book, as the author points out, is designed for the chemist who has already become acquainted with Russian grammar and pronunciation, but an introduction to the alphabet and phonetic pronunciation is nonetheless given. Considerable space is devoted to the transition of nouns to adjectives and verbs and the uses of prefixes and suffixes. In his introduction to grammar the author underscores its difficulty and makes helpful suggestions for reading and understanding chemical works. The conjugation of verbs and the use of prefixes that can change the meaning and aspect of words are taken up in considerable detail. The glossary consists of Russian technical terms, together with their root words and the English equivalents.

This glossary will be of great help to the student, and, as a matter of fact, it should be helpful not only to English-speaking chemists but also to Russian chemists desiring to know the English equivalents for Russian technical terminology. At any rate, I have found it of help to me.

There are very few inaccuracies: *superoxide* is translated into Russian as being *suboxide*; and Walden's *rotation* is given in Russian as Walden's *conversion.* These cannot be avoided in a first edition, however.

In general, the author is to be commended for having undertaken such a difficult work and for having produced such a good text. It can be recommended without question to English chemists desiring to learn scientific Russian.

V. IPATIEFF

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Scientific Russian Reader. Noah D. Gershevsky. xxii + 253 pp. $3.50. Pitman Publishing Co. New York and London.

THIS book is a compilation of more than one hundred brief excerpts from contemporary Russian writings in the fields of physics and chemistry. Within these fields, the excerpts are concerned with a wide range of subject matter. The book should prove helpful to moderately advanced students of Russian who wish to practice reading scientific material for the purpose of obtaining an extensive vocabulary of scientific terminology.

Each of the excerpts is provided with grammatical notes explaining the more difficult constructions and also with a list of selected words. A comprehensive vocabulary, and tables of the names of chemical elements and also of conversion factors for weights and measures, are included. The book does not contain a systematic grammar summary. The accent is not marked in the reading excerpts nor in the vocabulary.

J. W. PERRY

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FOR THE JUNIOR BOTANIST

Beginner's Guide to Wild Flowers. Ethel Hinckley Hausman. vii + 376 pp. $3.50. Putnam. New York.

IN THIS compact, pocket-size field book for the identification of Eastern wild flowers either by the juvenile or adult beginner, there are 1,080 excellent line drawings ($1\frac{1}{2} \times 2$ inches) of flowers, three to a page, with common and scientific names, a brief nontechnical description, time of flowering, and family name. The scientific names are based on Gray's *New Manual of Botany,* seventh edition. The common names are said to be "those most familiar through long folk usage according to Webster's New International Dictionary."

The flower figures are arranged in five color groups, namely: white or whitish, yellow or orange, pink or red, blue or violet, and green or brown. When a species has more than one flower color, the figure is repeated under the additional color sections with the result that forty-one species are repeated twice and two species three times, reducing the actual number of species illustrated to 1,045.

Beginners east of the Mississippi River will find in the book a large proportion of the wild flowers

they will encounter except rare species, species of very local distribution, and the many species of such large groups as the goldenrods, asters, and hawthorns.

It seems inevitable, however, that in such a popular book some very common plants would be overlooked, or missing because of a publication limit to the number of pages and illustrations, a larger proportion of the Southeastern species being missing than of the Northeastern. Among the more conspicuous omissions are: *Asarum virginicum, Clematis Viorna, Helleborus viridis, Hybanthus concolor, Hymenocallis occidentalis, Iris prismatica, Iris verna, Iris virginica, Lespedeza repens, Lespedeza frutescens, Lonicera Japonica, Oenothera laciniata, Papaver Rhoeas, Saxifraga micranthidifolia, Senecio Smallii, Spiraea sylvester,* and *Yucca filamentosa.* The book does illustrate, however, more species than any similar popular wild flower guide and will be found quite satisfactory for most beginners until they are sufficiently versed in the subject to need one of the more complete technical manuals.

P. L. Ricker

Chevy Chase, D. C.

THE SUBTILE FINE ART

Mathematics: Our Great Heritage. William L. Schaaf, Ed. xi + 291 pp. $3.50. Harper. New York.

THIS book contains a collection of sixteen essays by different authors, all of which have been previously published. These essays deal with the nature and cultural significance of mathematics. They have been selected and edited by Dr. William L. Schaaf, who has contributed a preface to the book and interesting introductory remarks to each of the essays.

In his preface the editor states that in selecting the essays he has had in mind the thoughtful reader who desires to understand why mathematics means so much to mankind. When the reader is a teacher or student of mathematics this selection is not a difficult task; but to provide interesting and readable essays on mathematics for the lay reader is a different matter; and in this respect Dr. Schaaf has been (in my opinion) remarkably successful.

The essays have been divided into five groups, each dealing with a different aspect of mathematics: its role as a creative art; its origin and development; its internal structure and intrinsic nature; its relation to science and technology; and its cultural and humanistic bearings. Of this collection I may mention three essays that particularly interested me: "On the Seriousness of Mathematics," by G. H. Hardy; "On the Relations of Mathematics and Physics," by Robert B. Lindsay; and "Industrial Mathematics," by Thornton C. Fry.

I noticed only three errors in the book, one of which is probably typographical; the others may mislead a nonmathematical reader. In the essay "Mathematics—the Subtile Fine Art," the statement is made that "no fractional numbers exist in Nature's building material." The reference is undoubtedly to atomic weights and to Prout's hypothesis (1816) that the atomic weights of the chemical elements would probably be found, by more precise measurement than was then possible, to be exact multiples of that of hydrogen. All through the nineteenth century this hypothesis was favorably regarded and gave rise to many redeterminations of atomic weights without finding any integral ratios; and in the twentieth century physical methods of making these measurements have been developed that are capable of much greater precision than chemical methods. It now appears that these ratios are all slightly different from whole numbers. For instance, assuming the atomic weight of oxygen to be 16, that of hydrogen is 1.00812. Although there may be no ratios expressible as common fractions, there are plenty of decimal fractions in nature's building material.

Again, in the essay "The Larger Human Worth of Mathematics," it is said that "it is an eternal truth that every integer is the sum of squares of four integers." But what about the number 3? This cannot be divided into four integral parts unless we suppose one of these parts equal to zero. It is not easy to understand what the author means by this statement.

On the whole, however, there is much of value in this collection of essays, and the book can be recommended to those who are interested in mathematics.

Paul R. Heyl

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LITTLE-KNOWN TRIBES

Economics of the Mount Hagen Tribes, New Guinea. Abraham L. Gitlow. Monographs of the American Ethnological Society, No. XII. xii + 110 pp. $2.75. J. J. Augustin. New York.

AS recently as 1933, the Mount Hagen area in the interior of New Guinea—next to Greenland the largest island in the world—was an unexplored and unknown land. With the coming of war in the Pacific, the north coast of New Guinea saw much bitter fighting. Nor did the interior remain outside the widely encompassing scope of World War II. In order to support air operations in the New Guinea theatre, a number of emergency landing strips were constructed in the central part of the island. Through the vicissitudes of war, Dr. Gitlow was dropped into the Mount Hagen region and was fortunately allowed a brief but productive period with the native peoples of the area. In this report he has assembled relevant published and unpublished material, together with his own information, and has prepared a concise and well-written account of the little-known Mount Hagen tribes.

The people of whom Gitlow writes live in a long upland valley whose western terminus is Mount Hagen. The valley is approximately 5,000 feet above sea level, and is bordered by high mountain ranges. Although New Guinea lies in the tropics, the altitude

of this rolling, grass-covered valley makes possible its temperate climate. The native inhabitants are agriculturalists, depending on the cultivation of the sweet potato and a number of subsidiary plant crops for their food, as well as on the raising of pigs. The entire valley is estimated to contain 125,000 persons, of whom about 25,000 live in the Mount Hagen area proper. This populous region is one the last frontiers to be affected by contact with the white man, a principal reason why its tribes hold a special attraction for the anthropologist.

In describing the economic aspects of Mount Hagen life, Gitlow uses a procedure that has proved to be fruitful in ethnology. Through experience, anthropologists engaged in ethnological work have found that a single aspect of a culture can be adequately understood only if its relations to the other most closely allied aspects of the culture are determined. Thus Gitlow comments as follows on his approach to presenting a valid picture of Mount Hagen economics: "It was necessary to take into account the facts of the physical environment, the institutional forces of the Mount Hagen society, the force of custom, habit, and tradition, and the highly complex and variegated range of motives to which the natives are subject."

For this reason, the author has included useful material on geography, social organization, and religion, as well as on economics alone. As an example of the close relation between "economic" and "non-economic" pursuits, we may note one of Gitlow's findings. Pig-raising is a significant element of economic life, for the pig is important both as a source of food and as a medium of exchange. Pigs are raised, however, primarily for a religious reason, for the sacrifice of the animal is necessary to establish relations of amity with the spirits, on whose good will depends the successful pursuit of Mount Hagen life. Fortunately, the spirits demand only the soul of the pig, which leaves the flesh to be consumed by humans. The incentives that motivate the Mount Hagen peoples in the economic aspects of their daily life are not, therefore, simple functions of economic self-interest, but are complex and various, and serve to show once again that "economic man" is not the uncomplicated fiction of earlier writers on economics.

The present book is not to be considered, however, —nor could it have been intended—as a complete account of the economics of the Mount Hagen people. The report is not based on an extended period of field work, and is consequently limited in its scope and in its penetration. Within the modest framework of his study, Gitlow assembled such relevant material as he was able to obtain. In so doing, he has produced an account that will be of real service to future field investigators; that will remain a useful survey of the peoples of the area; and that is today the most up-to-date report on the Mount Hagen tribes.

ALEXANDER SPOEHR

Chicago Natural History Museum